# Implicit learning of spatial context in visual search

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# Contents

## Summary

In the present experiments the paradigm of contextual cueing was used to investigate implicit learning of spatial context. The contextual cueing effect refers to the finding that in serial visual search tasks, the configuration of the target and the surrounding distractors can be learned implicitly, leading to faster target detection when configurations are repeated (Chun & Jiang, 1998).

The first two experiments in this work demonstrated that contextual cueing did not occur in a pop-out task but at the transition from preattentive to attentive search. Further experiments investigated the robustness of contextual cueing. The contextual cueing effect was robust against large jitter of the configurations and did not depend on conspicuous arrangements in the configurations. In addition, an unvaried stimulus-response association did not enhance the learning effect. In the last section, the experiments aimed at the question whether the configurations could be explicitly learned. Results indicated that configurations could be memorized explicitly and it showed that in the course of time, explicit learning effects increased more than implicit learning effects. In the last experiment, this finding was replicated and extended for more repetitions of the configurations.

To demonstrate that the contextual cueing effect is an implicit learning effect, results of a recognition test used by Chun and Jiang (1998) were replicated and an alternative recognition test was introduced which strengthened the former findings. Participants who were trained in the different tasks had remarkable learning effects of which they were not aware. Thus, results clearly demonstrated that contextual cueing is an implicit learning effect which is robust against a variety of manipulations.

"You know more than you think you know, just as you know less than you want to know." **Oscar Wilde** (1854-1900)

# 1. Introduction

## 1.1 Implicit learning

### 1.1.1 Definition

Just a small fraction of the stimuli detected by our senses enters consciousness. Most stimuli guide our behavior efficiently without ever reaching awareness. One process by which this knowledge is acquired is *implicit learning* and it is generally characterized as learning that proceeds both unintentionally and unconsciously (Shanks, 2004). Several characteristics distinguish implicit from explicit learning, summarized by Dienes and Berry (1997). Implicit learning in contrast to explicit learning shows specificity of transfer, in that implicit knowledge tends to be relative inflexible, inaccessible, and bound to surface features of the used material. Further, it tends to be associated with incidental rather than with intentional conditions and it usually remains robust across time. The corresponding storage mechanism is called *implicit memory*, which is defined as the facilitation of task performance through prior experiences in the absence of conscious or intentional recollection (Schacter, 1987).

Implicit learning and implicit memory are traditionally treated as two separate research areas with their own paradigms and views. In the recent past, areas started to converge and now many people think of implicit learning as a subset of implicit memory research (Buchner & Wippich, 1998), as can be seen in figure 1.1, which shows the modern classification of long-term-memory. It is involved when information has to be retained for intervals as brief as a few minutes or as long as a life-time. Long-term memory splits up into a declarative or explicit and a non-declarative or implicit part. If memory is a matter of consciously recollecting the past (e.g. the first day at school) or facts (e.g. the longest river in Europe), it is said to be expressed explicitly. Implicit memory is the kind of memory that shows up as an improvement on some perceptual, motor or cognitive task (skills), in priming or conditioning tasks or as already described in implicit learning.

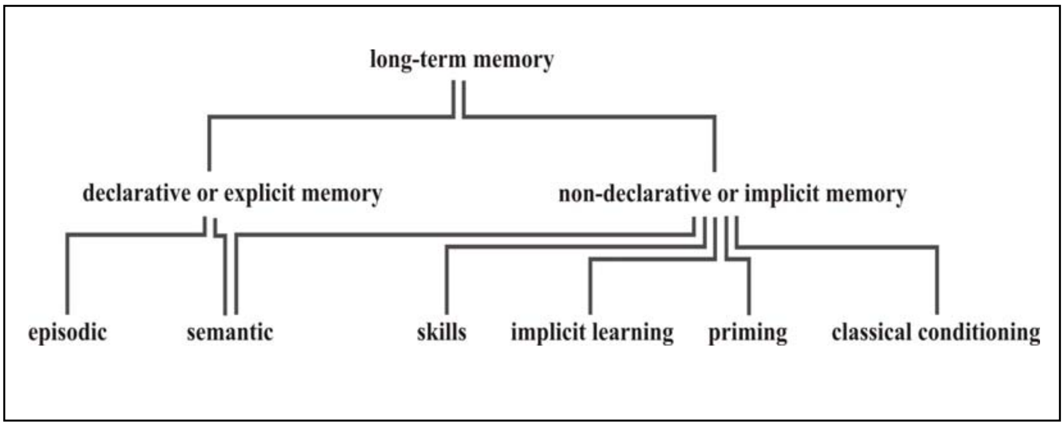


Fig. 1.1 Classification of long-term memory (adapted from Squire et al 1990).

### 1.1.2 Classical paradigms in implicit learning research

Research in implicit learning typically involves three components. First, there has to be an exposure to some complex rule-governed environment under incidental learning conditions. Second, it needs a measure that tracks down how well participants can express their newly acquired knowledge about this environment through performance on the same or on a different task. And third, there has to be a measure that assesses to what extent participants are conscious of the knowledge they have acquired (Cleeremans, Destrebecqz, & Boyer, 1998). The main classical paradigms will be described in the following.

The first paradigm that has been used intensively to investigate the acquisition of implicit learning is *artificial grammar learning* (e.g. Reber, 1967, 1976, 1989; Reber & Allen, 1978). In this paradigm, participants typically memorize strings of letters that appear arbitrary but are actually generated by a finite-state grammar. After the learning phase participants are informed of the existence of the complex set of rules that constrain letter order and are asked to classify new grammatical and nongrammatical strings. Classification performance is usually about 65%

which lies clearly above chance level which would be 50%. This indicates that participants have acquired substantial knowledge about the underlying grammar. Reber (1967, 1989) has claimed that a considerable portion of this knowledge is unavailable to consciousness.

Support for this idea has come from studies of amnesic patients (Knowlton & Squire, 1994, 1996). Although these patients perform poorly on explicit recognition tests of training stimuli, they are able to perform above chance as healthy participants in the above mentioned classification task. Not only do amnesic patients perform as well as controls, but their patterns of performance indicate that amnesic patients are using the same type of information to make grammar classification.

These findings show that artificial grammar learning can occur independently of explicit memory or knowledge of training exemplars. There is still some disagreement about whether this knowledge is entirely implicit. According to some researchers, the major part of the ability to classify new letter strings as grammatical or nongrammatical is based on conscious fragmentary knowledge of letter bi– or trigrams which build the grammatical strings (e.g. Perruchet & Pacteau, 1990).

Another paradigm to investigate implicit learning is *sequence learning*. Stimuli are typically given in context of a serial reaction time task. On each trial, participants see a stimulus appear at one of several locations on a computer display and are asked to press the corresponding key as fast and accurately as possible. Unknown to them, the sequence of successive stimuli follows a repeating pattern (e.g. Nissen & Bullemer, 1987). Reaction times tend to decrease progressively during practice and to increase dramatically when the repeated pattern is modified in any way (e.g. Cohen, Ivry & Keele, 1990; Curran & Keele, 1993; Reed & Johnson, 1994). This finding suggests that participants have learned the pattern and are able to prepare their responses based on their knowledge of the sequence. Still, they are often unable to verbally exhibit their knowledge of the sequence (Willingham, Nissen & Bullemer, 1989; Curran & Keele, 1993). This dissociation has led many authors to consider learning in this situation to be implicit.

A third paradigm often used in implicit learning research is *control of complex systems*. Prototypical is the use of computer implemented control tasks investigated by Berry and Broadbent (1984, 1988). In their experiments they gauged the combination of explicit and implicit learning processes on a single task. The participants had to manage a virtual sugar production factory by varying the number of workers employed and by interacting with a person from the union. The variables interacted in a previously defined manner. No information of the relations between any variables were given, thus participants had to find them out along the game. After gaining several target production levels it was investigated what knowledge participants had about relations. It was found that participants could express consciously direct relations but not indirect relations, which was astonishing, because the participants were able to carry out the task. Therefore, Berry and Broadbent (1988) concluded performance involves a subtle blending of explicit and implicit learning processes.

### 1.1.3 How implicit is implicit learning?

What all these paradigms have in common is that it is always difficult to prove that the knowledge the participants used to manage the task was truly implicit in its origin. One main argument of the skeptics is that one can probably not exclude explicit influences on performance, which is known in literature as the *contamination hypothesis*. The problem is therefore how to find the right control task that really proves that participants are not aware of the knowledge they are able to use. As Shanks (2004) put it: “It seems the case for implicit learning being unconscious depends crucially on the validity of the tests used to measure awareness.” A common distinction is drawn between *subjective and objective tests*. In the former participants are asked to report his or her state of awareness while in the latter they are usually demanded to make a forced-choice discrimination. There is little doubt that participants´ verbal reports in implicit learning experiments often fail to incorporate all of the information that can otherwise be detected in their behavior. Prominent examples are found in the artificial grammar research (e.g. Perruchet & Pacteau, 1990; Destrebecqz and Cleeremans, 2001). It is clear that above-chance classification performance does not require the rules of the underlying grammar to be known. It might instead be based on explicit knowledge of specific instances or chunks of the training strings.

Another distinction is made between *direct and indirect measures*. In a direct measure participants are explicitly instructed to perform the task of interest, whereas in an indirect measure the task performed is not part of the task definition. In other words participants are asked to perform another task than the task that is measured. Many researchers have considered properties of ideal direct and indirect tests of awareness (Reingold & Merikle, 1988; Jacoby, 1991; Jacoby, Toth & Yonelinas, 1993; Shanks & St John, 1994, Dienes & Berry, 1997), of which some will be described in the following.

Reingold and Merikle (1988) propose three criteria to test awareness. First, an adequate direct measure of the perceptual information available to awareness must be selected. Second, this measure must indicate null sensitivity and third, the measure of the perceptual processing/learning must be shown to have greater than zero sensitivity. Important is, that there is no consensus of what an adequate measure of awareness might be. Reingold and Merikle (1988) think that unconscious perception is demonstrated whenever an indirect measure shows greater absolute sensitivity than a comparable direct measure to a particular stimulus dimension. Methodological they propose that both measures should be made under comparable experimental conditions, otherwise, any observed dissociation may reflect an artifact rising from different measurement scales. Therefore, all characteristics as context and demands, except the instruction should be matched.

Shanks and St John (1994) have pointed out two criteria that characterize an adequate test. The first is the exhaustiveness criterion, which means that the test must be sensitive to all the conscious knowledge the participant has. The second is the information criterion which states that the test must measure the same stored knowledge that is actually controlling the behavior in the implicit measure. By this account, verbal reports for instance, fail both criteria. Participants might fail to report knowledge verbally held with low confidence. Further, verbal reports could probe participants about knowledge that they do not even need to perform the task.

Other researchers emphasized how implicit learning may be described best by presuming two thresholds (Cheesman & Merikle, 1984). They define a subjective threshold as the detection level at which participants claim not to be able to discriminate perceptual information at better than chance level. The second threshold is the objective threshold which is the detection level at which perceptual information is indeed discriminated at chance level. Dienes and Berry (1997) argue the subjective threshold criterion may encompass qualitatively different types of knowledge. They stress that first, implicit knowledge is more inflexible than explicit knowledge and does transfer seldom. Second, implicit learning occurs when attention is drawn on specific items and not on the underlying rules and third, that implicit learning is more robust and durable than explicit learning. According to this framework, learning is implicit when participants who perform above chance in a direct test lack metaknowledge, either because they believe they are guessing or because their accuracy is unrelated to their confidence ratings.

To summarize, it appears that the claim for implicit learning depends on the criterion one has chosen to assess awareness. Implicit learning seems to occur when awareness is simply assessed through verbal reports or through subjective criteria but is much more difficult to prove when measured by valid objective criteria.

### 1.1.4 A separate memory store for implicit memory?

Controversy still surrounds the question of whether multiple memory systems exist for explicit and implicit memory and whether the distinction between these two is based on conscious accessibility. Claims have been made that the different memory systems are subserved by different brain regions (Schacter, 1987; Schacter & Tulving, 1994). *Explicit memory* is described as the system which is consciously accessible in a fast, flexible manner. It depends on an intact medial temporal lobe system, including the hippocampus (Squire, 1992; Squire & Zola-Morgan, 1991). *Implicit memory* influences behavior in a less flexible but more stable manner without reaching awareness. It does not mainly rely on the medial temporal lobe system. Evidence for the distinction between the systems was found in studies of neuropsychological patients showing that individuals suffering from amnesia are impaired on explicit memory tasks but not on measures of implicit memory (Warrington & Weiskrantz, 1974, Scoville & Milner, 1957; Hamann & Squire, 1997). Most famous is the research initiated by Milner and Corkin and their colleagues in the 1960s. They demonstrated that the profoundly amnesic patient H.M. could acquire motor skills such as pursuit rotor and mirror tracing, even though he did not remember explicitly that he had previously performed the task (Milner, 1962; Milner, Corkin, & Teuber, 1968).

Recent evidence for distinct functional neuroanatomies of implicit and explicit memory comes from studies of Schott et al. (2005, 2006). In a functional MRI (Magnetic Resonance Imaging) study using a priming paradigm Schott et al. (2005) found implicit memory to be associated with hemodynamic decreases in left fusiform gyrus and bilateral frontal and occipital brain regions; whereas explicit memory was associated with bilateral parietal and temporal and left frontal increases.

## 1.2 Visual search

### 1.2.1 Definition

The visual system cannot fully process all of its input. Therefore, it developed two basic approaches to this problem. First, it discards information right in the beginning, for example the retinal image is processed in its full detail only at the fovea. The second approach is to process information selectively by using attention. When one wishes to look for a certain stimulus, he or she performs a *visual search* and attends to that stimulus. Visual search is one of the things we do all day. We look for our keys before leaving the house, we locate an empty parking space in a lot, we search for apples in the store, and so on. This mechanism is a powerful tool to guide our behavior efficiently.

### 1.2.2 Visual search paradigm

The most extensively used paradigm for studying the real-world visual behavior is the visual search paradigm. In the standard experiment, participants look for a target item among distractor items. The total number of items in the display is known as the set size. Participants usually report when they found the target. The two dependent measures that are most commonly studied are response time (RT) and accuracy. One measure of efficiency of the search is the slope of the function relating RT to set size. Searches can vary in their efficiency which will be described further in a section below.

### 1.2.3 Models of visual search

Accounts of visual search performance (e.g. Treisman & Gelade, 1980; Wolfe, 1994) typically assume that participants search through the items one by one, without retracing their steps. In order for this to occur, there has to be some memory mechanism that keeps track of previously attended items or locations. This assumption of memory-driven search is the core of the standard self-terminating *serial processing model* (Sternberg, 1969), which has entered almost all models of visual search performance with a serial component.

*Feature Integration Theory (FIT)* (Treisman & Gelade, 1980) proposed that visual search tasks can be dichotomized as preattentive or attentive. Preattentive processing was supposed to occur in parallel across the visual field in a single step. It is assumed to be limited to a small set of basic features like size, motion, orientation and color allowing for example to find a different colored item among black distractors instantly (See Figure 1.2, left). Preattentive search should be independent of set size. In contrast, attentive processing is necessary in tasks where target and distractors can not be kept apart by a single basic feature, for instance finding a rotated T among rotated Ls (See Figure 1.2, right). Search in these kinds of tasks would need to proceed in a serial manner, from item to item until the target was found. This could be seen in increasing RT when set size was enlarged. In other words, the most efficient searches are those in which the target is defined by a single basic feature and in which distractors are homogeneous, meaning the target "pops-out" of the display. The least efficient are those in which targets and distractors share the same basic features and/or when the distractors are heterogeneous (Duncan & Humphreys, 1989). Treisman has modified her original theory several times to accommodate new experimental findings, but the core statements described above were kept (for further details see Treisman, 1998).

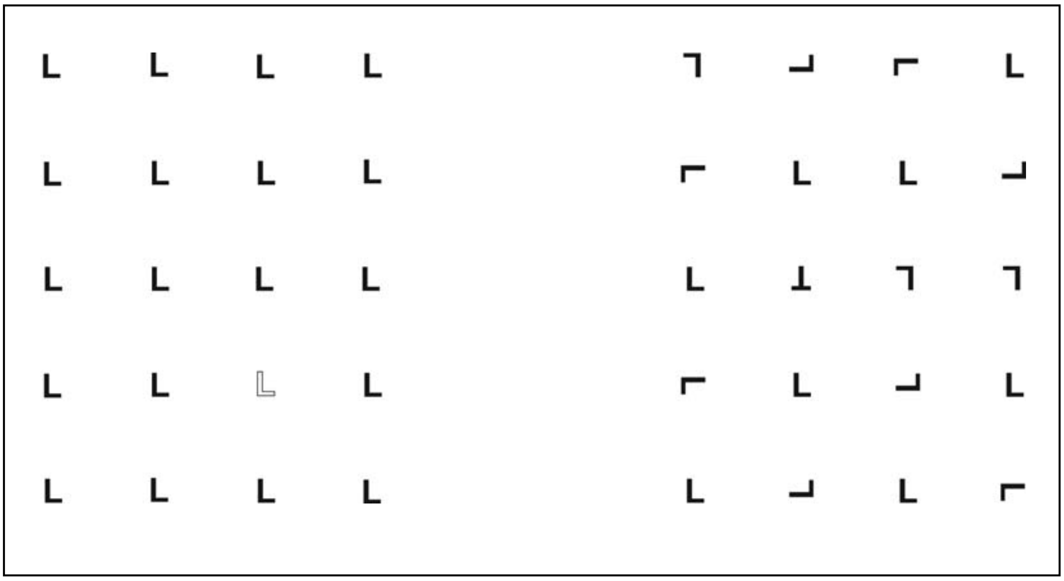

Fig. 1.2 Left: Example for preattentive or pop-out search. Right: Example for attentive or serial search.

Another prominent model in visual search research is the *Guided Search Model (GSM)* proposed by Wolfe (Wolfe, 1994; Wolfe, & Gancarz, 1996; Wolfe & Horowitz, 2004). It was developed as a response to the original FIT, which proposed that searches for conjunctions of two or more features should be serial. The data show that they often proved to be much more efficient than serial search would predict (Nakayama & Silverman, 1986), sometimes as efficient as presumed preattentive searches (Theeuwes & Kooi, 1994). The GSM kept the basic structure of the FIT, namely the preattentive and the attentive stage but assumes that preattentive processes could guide the deployment of the attentive stage. One of the mechanisms is bottom-up guidance to salient items. This mechanism is supposed to be stimulus-driven. The other mechanism is working top-down and is assumed to be under control of the searcher. Top-down control can, for example, be the response to the task demands. In the GSM, set-size effects are caused by the serial allocation of visual attention.

Data show therefore, that the world does not consist of two dichotomous categories in search tasks as Treisman originally anticipated. Intermediate search efficiencies occur when some feature information is able to guide attention, e.g. find the red T among red and green Ls. (Egeth, Virzi & Gabart, 1984).

## 1.3 Implicit learning in visual search tasks

### 1.3.1 Picture memory

In visual perception one could prove implicit learning by showing guidance of behavior, for example by a recognition effect for a picture. Simultaneously it must be demonstrated it was processed implicitly. However, we are very accurate at explicitly recognizing pictures we have seen just once before. When we see pictures of complex scenes with many different aspects in the picture, any of which could cause the feeling of familiarity, we can literally remember thousands of pictures for days and lesser numbers for over a year. When the pictures hold fewer different things that can be remembered about them, or are more confusable, performance deteriorates, but is still quite good (Rock & Engelstein (1959), Nickerson (1965), Standing, Conezio & Haber (1970), Goldstein & Chance (1971)). Therefore, one must find an experimental set-up that avoids explicit learning but allows concurrently implicit effects to occur.

Context in visual perception is very important. Not only configurations of illumination on the retina, but also our past experiences are taken into account in visual perception. For example, to be able to identify a bird against a background of trees and bushes, one benefits from prior exposure to general properties of the bird category. Research has shown also that we are better at recognizing an object if it is placed in the surrounding it is usually found in (Biederman, Mezzanotte, & Rabinowitz, 1982; Boyce, Pollatsek, & Rayner, 1989). Another study showed that when observers search for an object (e.g. pen) that is semantically consistent with its environment (e.g. desk), they make fewer eye-movements to detect the object than when they search for a semantically inconsistent object (Henderson, Weeks, & Hollingworth, 1999).

Further support for the importance of context comes from findings of Thomson, Robertson, and Vogt (1982). They took photographs of people in a number of different environments, such as walking into a shop or wearing a range of different clothing. Example pictures of such target persons were shown to the participants. In the test phase participants had to discriminate the original target persons from distractor pictures. It was manipulated whether the target person was in the original or a different environment and whether the clothing was same or different. For the distractor pictures the same was done vice versa, namely whether people were in the same or different environment or wearing the same or different clothing as the target person. Thomson, Robertson, and Vogt (1982) obtained powerful effects of the context on recognition. Nonetheless, smaller effects or no effects were obtained in recognition studies in the field of eyewitness research (Watkins, Ho, & Tulving, 1976; Woodhead & Baddeley, 1981).

### 1.3.2 Contextual cueing

Visual scenes are typically comprised of rich, detailed features, surfaces and objects. Powerful selection mechanisms must exist to focus attention on the regions of interest. There are still unsolved questions in the field of how and what details of a scene are implicitly memorized to guide further behavior. For example, what context features are important to form an implicit memory of a scene? Does implicit learning of scenes depend on conspicuous features? How robust is implicit learning against changes in the scenes?

Recently, an implicit learning paradigm in which learning of complex visual scenes is investigated was introduced (Chun & Jiang, 1998, 1999; Chun & Nakayama 2000; Olson & Chun, 2001). Chun and Jiang (1998) named this paradigm *contextual cueing.* Their basic proposal is that observers are exquisitely sensitive to visual information in a scene that remains invariant. Sensitivity to regularities in the environment would be informative because one can exploit the structure to coordinate behavior efficiently. Chun and Jiang (1998) used serial visual search tasks in which search displays are usually not repeated. They assumed though if one repeats the search displays that an invariant context can be defined as the spatial layout of the distractor items surrounding the target. This target and the surrounding distractors build a unique configuration which can be implicitly learned. It is claimed that during visual search an implicit memory is formed for the context which guides attention to the target in subsequent encounters. Thus, when the configurations are presented repeatedly this is supposed to lead to faster target detection.

In the contextual cueing paradigm, visual search tasks with novel arbitrary, otherwise meaningless configurations are used. Investigating natural scenes would be ideal to study real visual search behavior but Chun and Jiang (1998) claim that the use of reduced artificial scenes has several advantages. Influences of background knowledge and associations between items semantically related to one another can be ruled out this way. The method gives control over problematic parameters such as familiarity, similarity and object component salience.

Chun and Jiang (1998) had their participants search through configurations for a tilted “T” among heterogeneously rotated “L” distractors, a classic serial search task that typically leads to positive slopes in RT as a function of set size (e.g. Duncan & Humphreys, 1989; Wolfe, Cave, & Franzel, 1989). Each display contained 12 items which could appear within an array of 8 x 6 locations. The search array was randomly colored in an equal number of red, green, blue, and yellow items. The array subtended about 37.2° x 28.3° and each single stimulus in the array about 2.3° x 2.3° in visual angle. An example of a typical visual search array is given in figure 1.3.

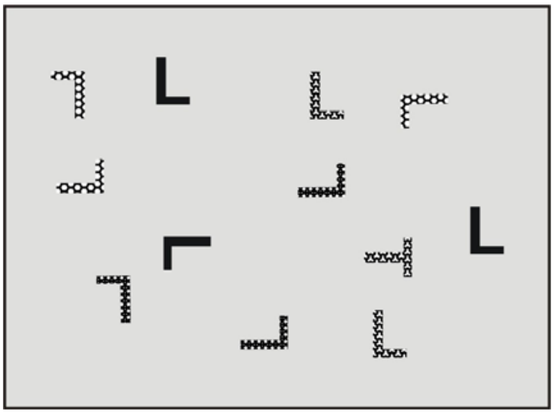

Fig. 1.3 Schematic example of a typical visual search array used by Chun and Jiang (1998). The differential shading represents the different colors (red, green, blue, and yellow) used for the items.

Each trial contained one of two possible targets ("T" tilted to the left or to the right), and participants were instructed to press a response key corresponding to the appropriate target. Whether the "T" was tilted to the left or to the right was randomly chosen for each trial and each configuration. Thus, any priming effects of the attributed response could be excluded.

The experiment was subdivided in 30 blocks. Half of the configurations used in one block were repeated across blocks (old), the other half were configurations that were created anew every trial (new). The target in each of the repeated configurations appeared in a consistent location relative to its context distractors. Thus, old configurations were repeated for thirty times in the experiment and the global spatial layout provided a cue to predict the location of the target. The primary measure was the RT to react to the target. Chun and Jiang (1998, Experiment 1) obtained a significant benefit for target search performance in repeated configurations. This benefit was defined as the *contextual cueing effect*. Their results are depicted in figure 1.4.

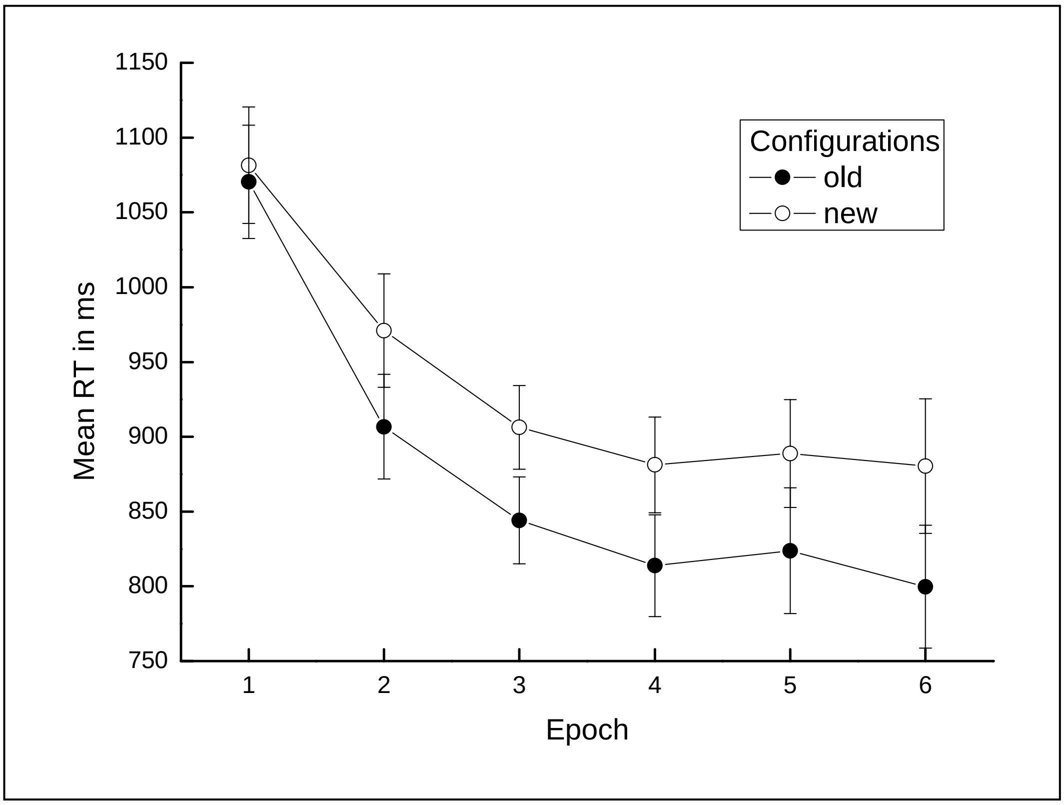


Fig. 1.4 Results of Chun and Jiang (1998, Experiment 1). Shown are mean RTs for repeated (old) and new configurations across repetitions (Five repetitions of old configurations = One epoch). Error bars represent the standard error of the mean.

Chun and Jiang (1998) showed further that this contextual cueing effect is not due to surface features of the items but that the spatial arrangement of the stimuli alone is sufficient. Furthermore, faster target detection is gained through training, but the effect is instance-based, which means it occurs only when the same spatial target-distractor configuration is repeated. This effect is robust against some distortion of the arrangement, occurs even when the configurations were flashed for only 200ms (Chun & Jiang, 1998), and implicit knowledge is preserved for at least one week (Chun & Jiang, 2003). Remarkably, an explicit recognition test which was conducted after the main experiment showed that participants could not discriminate the repeated configurations from new configurations above chance level (Chun & Jiang, 1998), nor could they predict the monitor quadrant in which the target was to occur when it was substituted by a distractor stimulus (Chun & Jiang, 2003). In the opinion of Chun and Jiang (1998) contextual cueing is therefore driven by implicit memory representations tuned by past visual experience.

The findings were further extended by Olson and Chun (2002) who investigated what counts as context. Are all distractor items necessary to cue attention or does local context around the target suffice? Olson and Chun (2002) tested this by varying the repeated configurations. Only half of each configuration remained invariant, and the other half changed randomly across repetitions. The target was either embedded within the invariant side or within the random side. Contextual cueing was only observed when the side containing the target was the invariant one suggesting that local context is sufficient.

Jiang and Chun (2001) presented red and green distractors intermixed within the configuration. Each participant was assigned to one of the colors and instructed to attend only to that color, because the target they had to look for appeared always in that color. Thus for any given configuration, half of the items were attended and the other half was not. It was varied whether the attended or the unattended context was repeated. Contextual cueing was only found when the target was within the attended unchanging context. Jiang and Chun (2001) stressed the importance of selective attention even within implicit learning tasks. They proposed that when contextual information is encoded in the real world, learning is restricted to the most relevant subset of items. Jiang and Leung (2005) replicated the results but went further by extending the task with a transfer phase. After they found, participants showed no contextual cueing for the repeated ignored context, they turned it into the relevant one by changing the color of the target into the color of the ignored context. When the previously ignored set becomes attended, it immediately facilitates performance. In contrast, when the previously attended context becomes ignored, it no longer enhances search speed. Jiang and Leung (2005) concluded that the expression of visual implicit learning depends on attention, but latent learning of repeated information does not.

Jiang and Wagner (2003) tested whether participants learned to associate the target location with the overall configuration of the distractors or with the individual location of each distractor. Participants were trained to associate one target location with two sets of distractor locations on separate trials. After training participants showed perfect transfer to recombined configurations. Those were created of half of one trained distractor set with half of the other trained distractor set. In a second experiment participants showed not perfect but good transfer from trained configurations to rescaled, displaced and perceptually regrouped configurations. Jiang and Wagner concluded that the relative locations among items were also learned. Thus, both individual target-distractor associations and associations about whole configurations are learned in contextual cueing.

In the real world, we are living in rich temporal structure that guides our expectations. The classic example is the perception of a moving ball. This movement follows certain regularities and allows us therefore, to predict the future of the ball. Consequently, the contextual cueing paradigm was also investigated under conditions of moving objects. Chun and Jiang (1999) studied this in a dynamic search task, where participants were asked to quickly detect a T target that was moving about amongst other moving L distractors. Although the movements of the items seemed random, for half of the configurations, the target trajectory was perfectly correlated with the distractor trajectories while in the other half, all trajectories were uncorrelated. Participants were faster to detect targets in correlated configurations although they could not discriminate between correlated and uncorrelated configurations.

By monitoring eye movements Peterson and Kramer (2001) investigated how contextual cueing occurs. Fewer fixations were needed when the participants viewed the repeated configurations even in trials when the eyes failed to immediately detect the target. Peterson and Kramer (2001) concluded that contextual cueing is able to guide attention to the important areas of a scene.

However there are visual search tasks in which familiarity does not enhance search efficiency. Wolfe, Klempen, and Dahlen (2000) made a series of experiments in which participants had to search through a display (e.g. uppercase letters) to check whether a target was present or absent. The cue which indicated what target to search for was also present in the display but was not identical to the target (for instance lowercase letter), which excluded visual matching. The astonishing finding was that search in the repeated displays even after 350 repetitions was no more efficient than in non-repeated displays. The configuration of results was reproduced in several search tasks. (Wolfe et al. 2002, Wolfe (2003)). Recent experiments (Oliva, Wolfe, & Arsenio (2004)) challenged the question whether these findings were due to general superiority of vision over memory use. Results indicated that observers made a pragmatic choice between vision and memory. A strong bias towards visual search was found even in the presence of well-known visual stimuli. Oliva, Wolfe, & Arsenio (2004) argued that the answer may lie in the cost of coordinating memory and visual search. When the observer uses memory to guide a visual search it may take longer than an inefficient visual search within a small set size.

To summarize, contextual cueing is a paradigm for studying how regularities are learned through perceptual experience, and how such visual knowledge facilitates behavior such as search. Research is tracking the neurophysiological basis of contextual cueing within the human brain which is described in the next section.

### 1.3.3 Neurophysiological manifestations of contextual cueing

Olson, Allison & Chun (2001) collected electrophysical recordings from the cortical surface of patients monitored for epileptic seizure foci. The contextual cueing paradigm was used and patients showed the expected RT advantage of repeated over new configurations. Because the paradigm was used as described by Chun and Jiang (1998), and thus no other visual cues existed to distinguish repeated from new configurations, any difference in neural activity must reflect differences between the two types of trials. A difference in the N210 component of the ERP waveform was found, which demonstrates influences of learned information within 210 ms of stimulus onset. Moreover, due the higher resolution of the intracranial recordings, Olson, Allison & Chun (2001) demonstrated that much of this differential activity occurred in early visual areas such as V4, V2 and perhaps even V1. In their opinion, the N210 reflects not modulation of activity within the initial volley of visual information through visual cortex, but rather backward feedback from higher-level stages, presumably scene representations in medial temporal cortex. It remains unclear whether the N210 reflects the discrimination of repeated and new configurations or whether it signals the top-down control of spatial attention to the target associated with a repeated configuration.

Chun and Phelps (1999) questioned the notion of multiple memory systems for implicit and explicit memory by showing that amnesic patients who were thought to manifest only explicit memory deficits were impaired on an implicit memory task. In their study amnesic patients with medial temporal system damage (including the hippocampus) performed a contextual cueing task. They showed standard implicit perceptual learning in that their performance improved over time but no contextual cueing, suggesting a selective impairment for learning contextual information. Using the same task Manns and Squire (2001) showed when damage is confined largely to the hippocampal formation, contextual learning was intact. Therefore, results remain unclear part of because the configuration of brain damage varies heavily across patient studies.

Park, Quinlan, Thornton, and Reder (2004) used a neuropharmacological approach that induced temporary amnesia in healthy participants, with each participant serving as his own control. This procedure avoided problems with varying brain damage in neurological patients. Under the influence of the benzodiazepine midazolam participants did not show contextual cueing effects although a general speed-up in performance across time was found. Taken together, the results call into question that multiple memory systems should be distinguished on the basis of conscious accessibility.

Attempts have been made to identify areas in the brain were contextual cueing takes place. Chun (2003) proposes the perirhinal cortex, which is located at the ventromedial aspect of the temporal cortex as a promising candidate. In the animal brain it plays an important role in both perception and memory of objects, especially in building associations among objects (Gaffan & Parker, 1996; Murray & Bussey, 1999; Murray & Richmond, 2001).

## 1.4 The present experiments

The following experiments are based on the theories and methodologies described previously. On one hand it was attempted to avoid methodological problems of older studies and on the other hand to extend knowledge in this research field. The experimental method is inspired by the experiments on contextual cueing made by Chun and Jiang (1998, 2003).

Contextual cueing was demonstrated in a variety of tasks but always within a serial search process. An interesting question is whether the effect can be shown in a preattentive search or put different, what happens when the target pops out of the configuration? As described, context plays a minimal role in those searches but may nevertheless lead to faster target detection. This is investigated in *Experiments 1a, 1b and 2.*

Chun and Jiang (1998, Experiment 5) found that repeating the context but moving the target across all possible distractor positions did not lead to contextual cueing. Thus, repeating the configuration alone does not produce faster target detection but the unique configuration of target and surrounding distractors is needed. This important finding was replicated in *Experiment 3* with the intention to use the condition with the freely varying target as the baseline in the following experiments.

In Experiment 6, Chun and Jiang (1998) found learning occurs when configurations are jittered anew in every trial. It remained unclear whether the effect is influenced by jitter in a systematic order. In *Experiment 4* jitter was investigated as an independent variable. Further, the allegation implicit learning is often confronted with, is that the learning effects are based on fragmentary conscious knowledge. As a retort, a new explicit recognition task was constructed which tested for explicit knowledge of the configurations. This test was used from Experiment 3 on.

It is unclear whether all possible display configurations can be implicitly learned. It may be that some configurations with conspicuous arrangements are those that produce the contextual cueing effect and that configurations that are not distinctive in a certain way can not be learned because they look all the same. This was investigated in *Experiment 5*. Inhomogeneous and homogeneous arranged configurations were contrasted. The former should lead to larger contextual cueing effects and should be easier recognized in a recognition test.

In all experiments dealing with contextual cueing the response to the target was always uncorrelated with the repeated context. In other words, a repeated configuration did never predict what answer had to be given. But would an unvaried response enhance the effect or would contextual cueing alone be such a strong mechanism that repeating the answer would not change the results? *Experiment 6* investigated this question.

To gain further insight into whether the contextual cueing effect is truly implicit a finding of Chun and Jiang (2003) was further explored. They told their participants in advance that some configurations would repeat but found no effect on the contextual cueing effect. Further, participants could still not discriminate repeated from new configurations or predict the monitor quadrant of the target in a certain trial. In *Experiments 7a, 7b and 7c* participants were told that some configurations would repeat and requested to memorize them. The question was whether configurations could be learned explicitly and if yes, would explicit learning of configurations differ from the implicit learning effect?

# 2. Implicit learning of spatial context in preattentive search

## 2.1 Experiment 1a

### 2.1.1 Introduction

So far contextual cueing (e.g. Chun & Jiang, 1998, 1999; Chun & Nakayama 2000; Olson & Chun, 2001) has been shown in a variety of studies but always in serial search tasks. It remains unclear whether influences of context can be found under circumstances where participants do not have to search through the whole configuration to detect the target. A possible real-world example is: If you are looking for a screwdriver with a red grip in a toolbox, which is catching your eye immediately, because all the other tools have blue grips, does it help you if you know what the toolbox looks from the inside, because you have seen it before? On one hand, it is possible that in such a fast search process the context, even if it is well known, does not play a role. As proposed in the FIT (Treisman & Gelade, 1980) preattentive processing is supposed to occur in parallel across the visual field in a single step and thus context influences might be unimportant. On the other hand, the well known context might support also this kind of search and makes even more efficient behavior possible.

The aim of the first experiment was therefore to investigate whether implicit learning of spatial context can also occur in a preattentive or pop-out search. Therefore, serial and pop-out search were contrasted within the same experiment. The second aim of this experiment was to replicate the contextual cueing effect in a serial search with newly created stimuli, which were used in all following experiments. To test for true implicit learning effects in this experiment, participants were asked after the experiment whether they had noticed repetition of configurations.

### 2.1.2 Materials and Methods

*Participants.* 11 (four male) participants, aged 20 - 37 years (mean: 26.27), took part in the experiment, either as a course requirement or as volunteers. Vision was normal or corrected-to-normal.

*Apparatus.* Stimuli were presented black on light blue on a 85 Hz Iiyama Vision Master 407 monitor (17’’). Screen resolution was 800x600 pixels. Presentation durations were controlled by Presentation©, running on a personal computer. Distance between monitor and the eyes of the participant was 80 cm. Responses had to be given with the two control keys of the keyboard.

*Task.* Participants had to search for a target stimulus within a search configuration. As soon as the target was located they were to respond with the corresponding key.

*Design.* Search type was blocked and varied as the main independent factor. Search types, serial and pop-out, occurred with equal probability. Across blocks search types were randomized. Ahead of every block search type was signalized. The second independent variable was Configuration with the factor levels Repeated or New. Repeated and new configurations were randomized within a block. Block was treated as an independent variable which allowed observation of the learning effects across time but for easier comparison with Chun and Jiang (1998) block was represented in epochs. Five blocks were grouped into one epoch.

*Material.* Each search configuration consisted of 12 black squares, each having a vertical white line in the middle. The target square had a vertical line shifted either to the left or to the right. In preattentive search, the line on the target square was broken, which ensured immediate pop-out. The background was set to light blue. Item locations were determined by an invisible 8 x 6 grid that subtended 17.8° x 12.8° in visual angle on the monitor (see figure 2.1). This allowed only certain positions and ensured that squares did not overlap. The size of each of the squares was about 1.4° x 1.4° in visual angle. Each item was jittered in vertical and horizontal direction anew every trial (by a maximum of 25 pixels). Jitter avoided collinearities in configurations. Ahead of the experiment, repeated configurations were determined with a random generator for every participant separately. Thus, every participant had a different set of repeating configurations. For examples of possible configurations see figure 2.2.

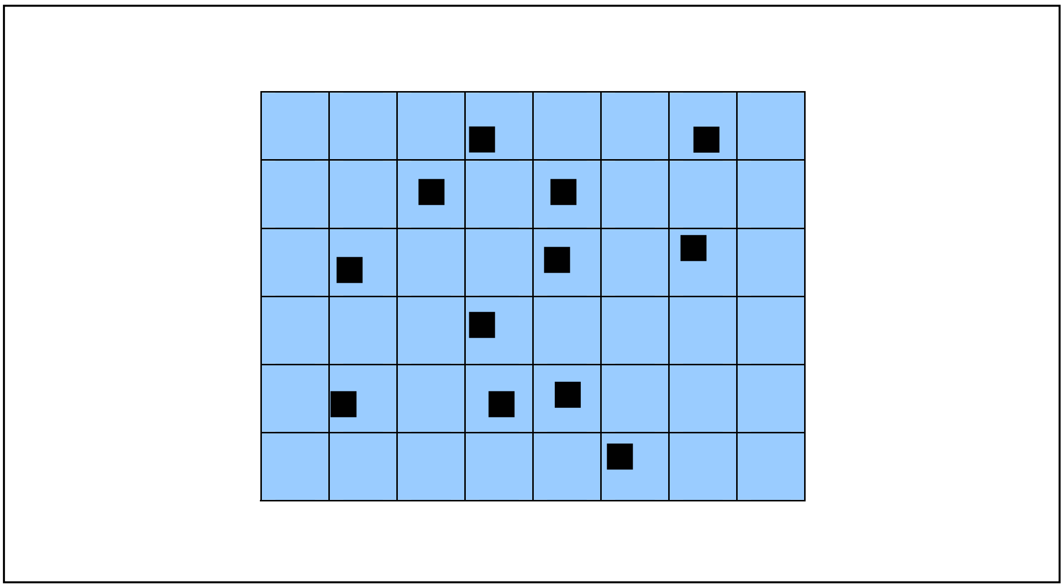

Fig. 2.1: Schematic example of jittered item locations within the 8x6 grid. The grid was not shown on the display.

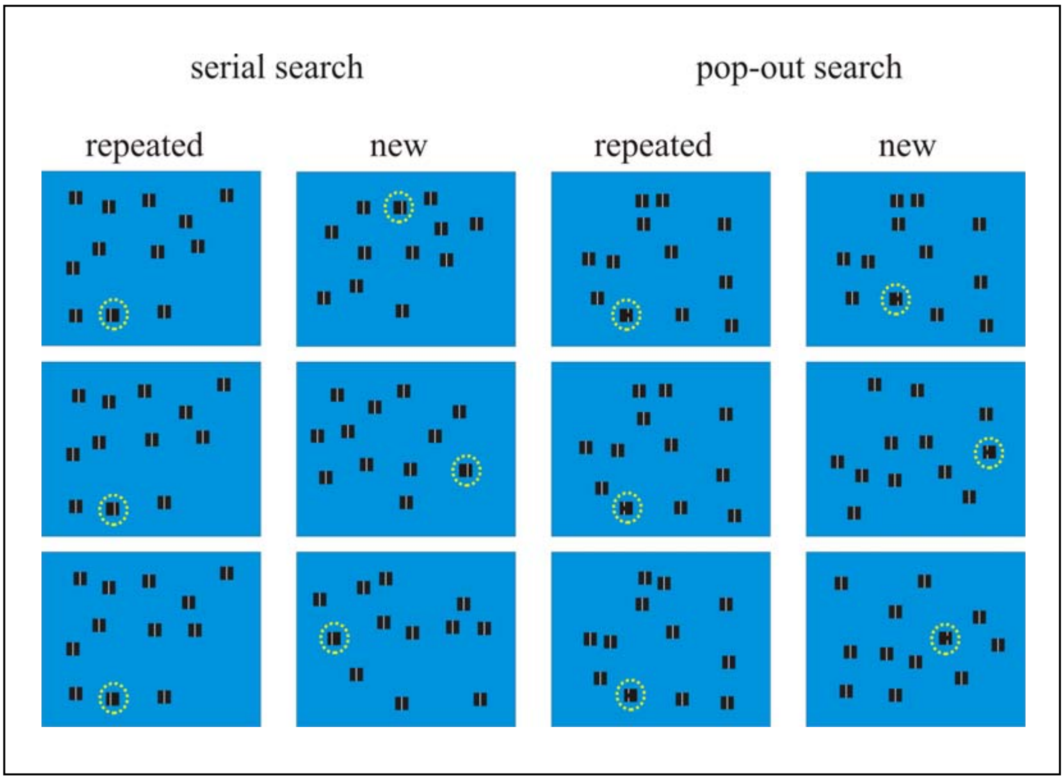


Fig. 2.2: Examples of configurations used in Experiment 1. The two columns on the left show repeated and new configurations as used in serial search and the two columns on the right show examples for pop-out search. The target is marked with a yellow circle which did not appear on the display. As can be seen in repeated configurations items were jittered up to a maximum of 25 pixels from block to block.

*Trial procedure.* Trials started with a fixation cross lasting 1s presented in the middle of the monitor display. Next, the search configuration was presented until a response occurred (see figure 2.3).

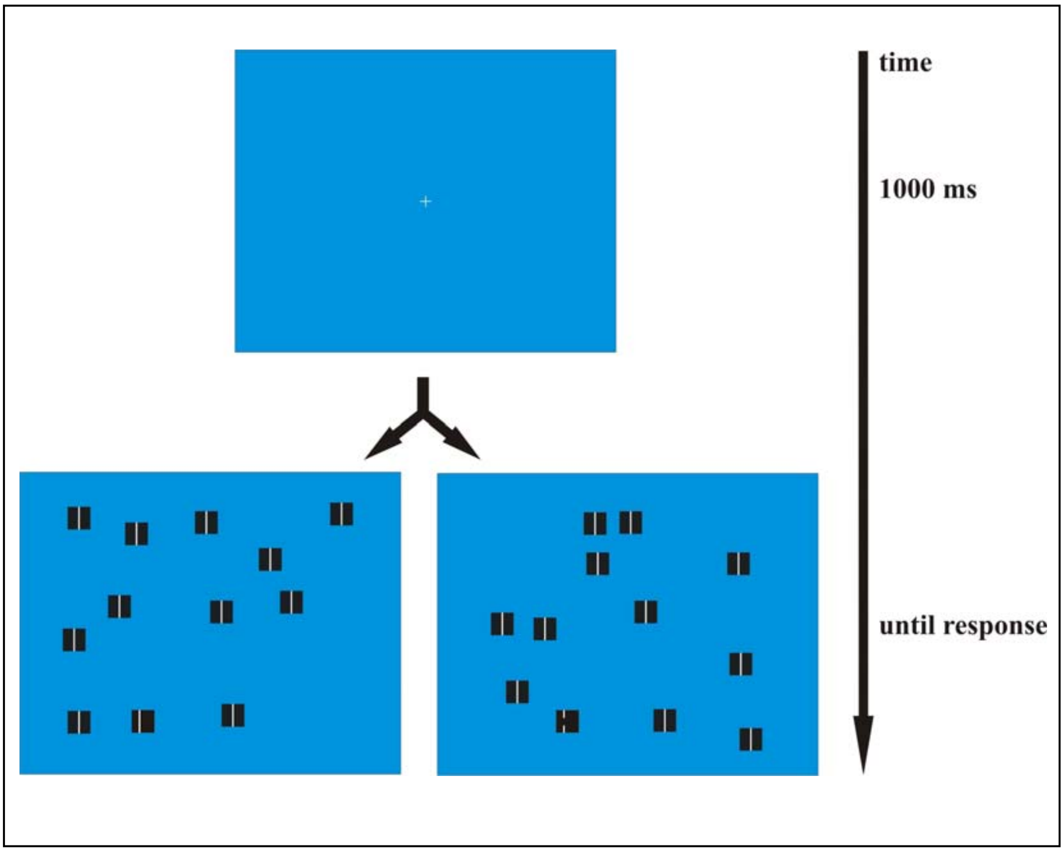


Fig. 2.3: Trial procedure with examples of stimuli used in Experiment 1. Bottom left: serial search, Bottom right: pop-out search

*Instruction.* Participants were instructed to fixate at the fixation cross first. The task was then to find the square on which the line was shifted from the middle. They were to respond with a left button press when the line was shifted to the left or with a right button press when the line was shifted to the right. Two different search types appeared in separate blocks. Participants were to react as quickly and as accurately as possible. They were not informed that half of the configurations would repeat.

*Layout of experimental sessions.* The experiment was organized in two sessions with the constraint that both had to be completed within three days. Each session consisted of 30 blocks with 24 configurations, summing up to a total of 1440 trials. The experiment started with a warm-up block consisting of 12 trials, which were excluded from analysis. After each block, mean RT and mean error rate were presented. After feedback was given participants were free to rest or directly proceed with the next block. There was a mandatory break of five minutes in the middle of the experiment. One session took about 50 minutes. After the two sessions participants were asked what they believed was the purpose of the experiment and whether they had noticed repetition of any configuration.

*Data analysis.* In this and the following experiments, incorrect trials were eliminated. RT data were trimmed and winsorized on a 10% level on each side of the distribution separately for each participant (Wilcox, 1995). RT data which were treated as distributed normally were analyzed with methods for repeated measures, usually a repeated-measures analysis of variance (ANOVA) and pairwise comparisons when appropriate. To avoid multiple comparison problems post-hoc tests are reduced to a minimum. F-Values are corrected after Huynh-Feldt if necessary (violation of sphericity) but for better readability degrees of freedom are reported uncorrected. Error bars in graphs are based on the standard error procedure proposed by Loftus and Masson (1994).

Two measures for contextual cueing are analyzed. Chun and Jiang (1998) defined the net *contextual cueing effect* as the difference in mean RT between new and repeated configurations. The *magnitude of contextual cueing* they defined as the difference between repeated and new configurations collapsed across the last three epochs.

### 2.1.3 Results

Overall error rate in this experiment was very low (1.8%). In absolute numbers, there were 282 errors in 15840 data sets which is less than one error in every second block per participant. These are too few observations for an analysis. Thus, error rates were not further investigated. Serial search and pop-out search were analyzed separately.

*Serial search:* Mean response times are shown in figure 2.4. Participants improved throughout the experiment. A behavioral advantage for repeated configurations started from about Epoch 3 on, as evidenced by shorter RTs when responding to repeated compared to new configurations. Thus, participants responded faster as they familiarized with the task but much faster to repeated configurations and this effect even enlarged with more repetitions. This was confirmed by an ANOVA with factors Configuration and Epoch. The main effect of Configuration was significant [$F(1,10)=13.69$, $p=0.004$]. General speeding of the task is reflected in the significant main effect of Epoch [$F(5,50)=16.88$, $p<0.001$]. Most importantly, the contextual cueing effect is expressed by a significant interaction between Configuration and Epoch [$F(5,50)=5.80$, $p=0.003$].

Planned post-hoc comparisons restricted to first and last epoch demonstrated a significant interaction between Configuration and Epoch [$F(1,10)=20.56$, $p=0.001$]. Pairwise comparisons showed that repeated and new configurations do not differ from another in the first epoch [$t(10)=-2.05$, $p=0.68$] but repeated were significantly different from new configurations [$t(10) =5.78$, $p<0.001$] in the last epoch. This stressed that repeated configurations were not easier configurations. The contrary holds in Epoch 1, the almost significant negative t-value indicated a trend that repeated configurations took longer to react to in the beginning. These results confirmed that contextual cueing is an effect that emerges after training.

*Pop-out search:* The mean response times are shown in figure 2.5. Participants improved throughout the experiment in this condition, too. As can obviously be seen, participants responded faster as they familiarized with the task but not faster to repeated configurations compared to new configurations as in serial search. Thus, no contextual cueing effect was found. This was confirmed by the ANOVA including factors Configuration and Epoch. The main effect of Configuration did not reach significance [$F(1,10)=0.29$, $p=0.602$]. General learning is reflected in the significant main effect of Epoch [$F(5,50)=11.46$, $p<0.001$]. The significant interaction between Configuration and Epoch that would indicate contextual cueing failed to reach significance [$F(5,50)=0.64$, $p=0.671$].

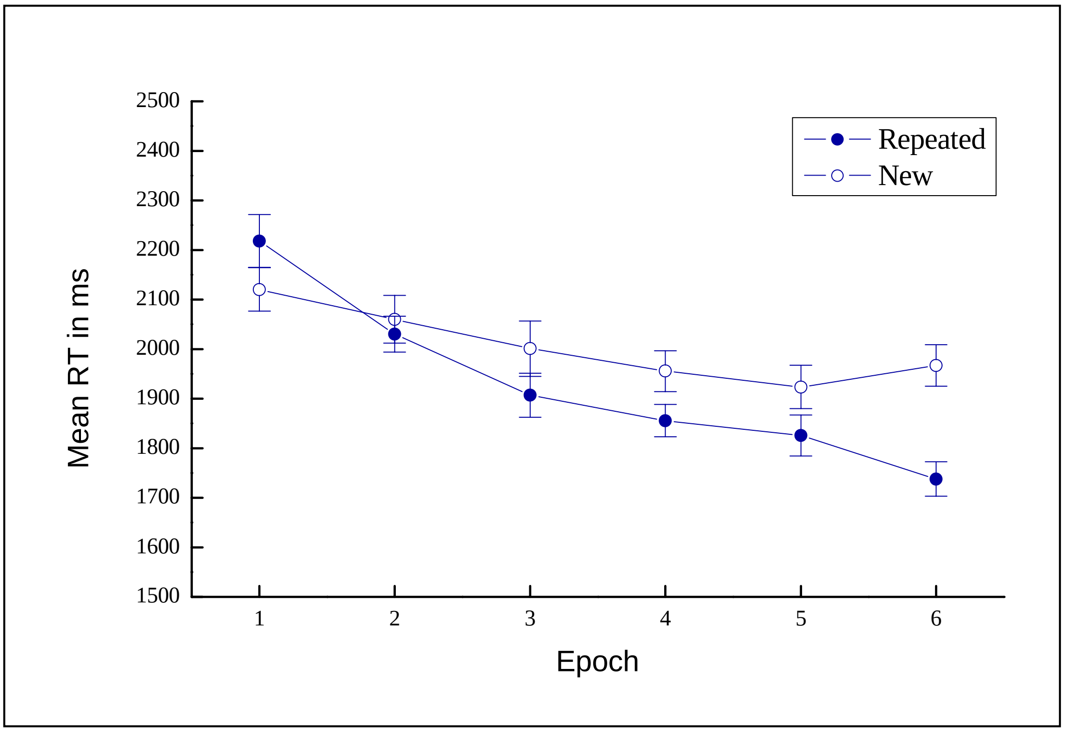


Fig. 2.4: Mean RT in condition serial search across epochs

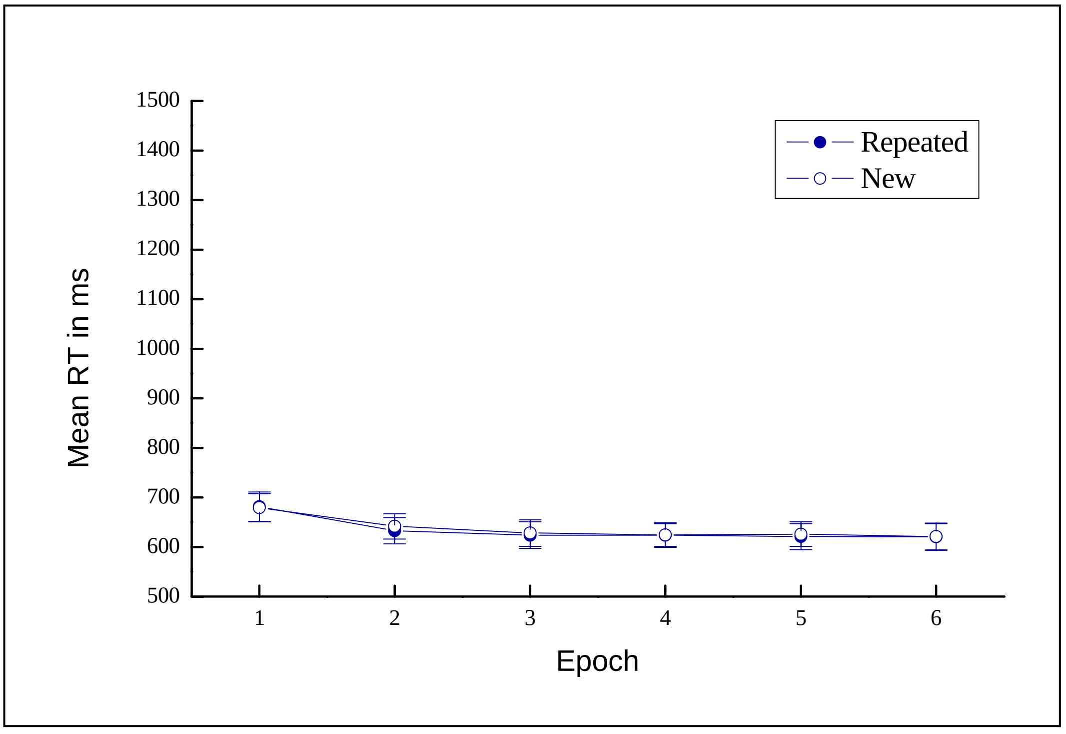


Fig. 2.5: Mean RT in condition pop-out search across epochs

*Contextual Cueing:* The effect was evident in every single participants´ data in serial search but not in pop-out search. The net effect which is the difference in mean RT between new and repeated configurations is shown in figure 2.6. For serial search the magnitude of contextual cueing (the difference between repeated and new configurations collapsed across the last three epochs) was 142ms which differs significantly from 0 [t(10)=4.14, p=0.002] and for pop-out search it was 2ms in this experiment which is non-significant [t(10)=0.30, p=0.769].

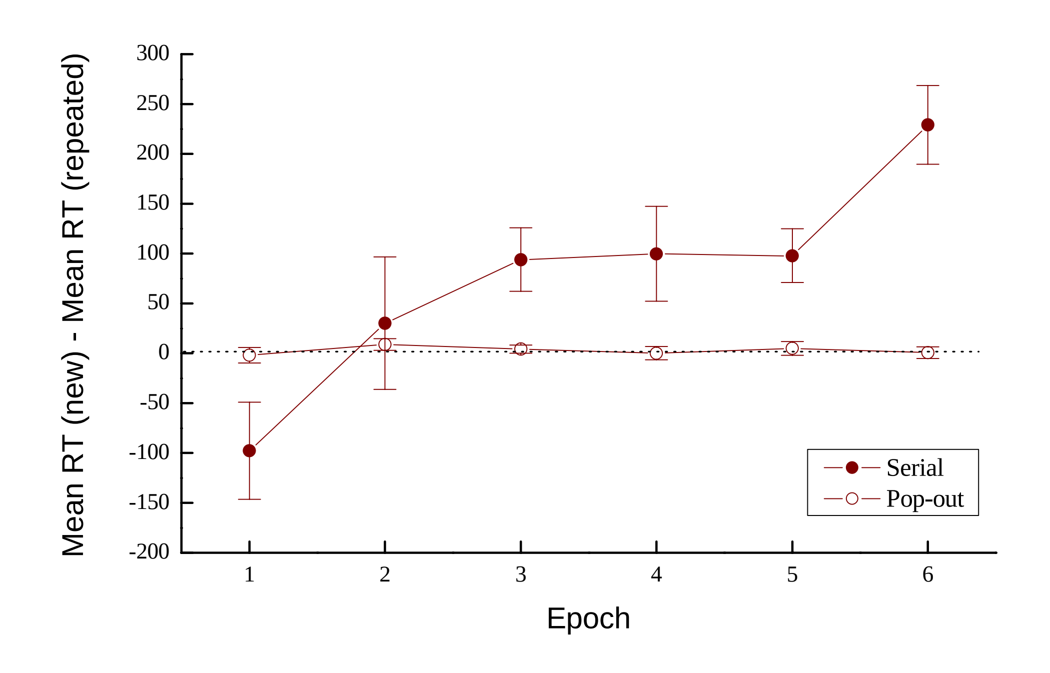


Fig. 2.6: Contextual cueing effect (Mean RT new configurations – Mean RT repeated configurations) in serial and pop-out search across epochs

*Evidence for implicitness:* None of the participants guessed the main purpose of the experiment. When asked whether configuration repetition was noticed, none of them did. Only seven of the 11 participants were debriefed after the experiment. The others were debriefed after Experiment 1b.

### 2.1.4 Discussion

The contextual cueing effect in serial search was replicated. From about Epoch 3 on which was the 15$^{th}$ to 20$^{th}$ repetition, participants started to find the target faster in repeated configurations than in new configurations. The effect even enlarged in the following. This indicates participants implicitly learned the configuration of target and distractors in the repeated configurations along the experiment. Importantly, search performance for the two configuration types was the same in the first epoch. The results extend the findings of Chun and Jiang (1998) concerning the jitter of the items. They showed that contextual cueing can still be obtained when the items in the configurations are allowed to jitter up to 12 pixels in both horizontal and vertical direction anew every trial. Though items were jittered up to 25 pixels in this experiment in both horizontal and vertical direction anew every trial a large contextual cueing effect was obtained.

The most noteworthy and new result is that in pop-out search no contextual cueing effect evolved. Although participants became faster which is evidenced by the main effect of Epoch, it seems they did not benefit from repeated configurations. To conclude, participants did not implicitly learn anything would be premature though. As expected, search performance for serial and pop-out search differed extremely. In pop-out, searching and finding the target was a lot easier. Responses were made about 1.5s faster. Mean RT in the last epoch was about 620ms which might be as fast as one can get in this kind of experiment. This does not necessarily mean one could not learn the distractor configuration. It could simply mean one does not need to learn it, because behavior is as efficient as possible. Thus, a ceiling effect can not be excluded. An analysis of this problem is made in Experiment 1b.

The evaluation of implicitness showed that none of the participants that were already debriefed, noticed that configurations repeated. This result indicates that learning in this experiment occurred without awareness as already shown in the other experiments by Chun and Jiang (1998, 2003). Yet, one can doubt whether learning was indeed implicit since verbal reports are not very valid. In the following experiments, it will be confirmed that learning was incidental by an objective recognition test.

A possible criticism in Experiment 1a is that in the new configurations targets varied freely across all possible locations. Chun and Jiang (1998) pointed out that this could be a problem for the interpretation. If in repeated configurations target positions are kept unvaried and allowed to vary freely in the new configurations, contextual cueing could be due to learning the target locations of the repeated configurations alone and not the association between those and the context. To meet this objection, location probabilities were also kept constant for new configurations from Experiment 2 on.

## 2.2 Experiment 1b

### 2.2.1 Introduction

The purpose of Experiment 1b was to investigate whether in pop-out search configurations were implicitly learned but knowledge did not lead to a contextual cueing effect. Participants could either have made no use of their knowledge because their responses were already as fast as possible (ceiling effect), or configurations were not implicitly learned because pop-out alone leads to the most efficient behavior. To test the two alternatives, participants of Experiment 1a were requested to add a third experimental session in which their repeated pop-out configurations were used in the serial search condition, and vice versa. If a contextual cueing effect was present from the first epoch on in the now serial search, one could conclude that the configurations had been learned in the pop-out condition but participants made no use of their knowledge. A second alternative would be that the contextual cueing effect is not present from Epoch 1 on but maybe from Epoch 2. The conclusion would be that former pop-out configurations were not implicitly learned completely but a savings effect makes it easier to learn them now. An analogy can be drawn to the findings of Jiang and Leung (2005) that previously ignored distractors facilitate performance when they suddenly become attended. The third alternative would be that participants develop contextual cueing regularly which would lead to the conclusion that former pop-out configurations were not learned in Experiment 1a.

The former serial search configurations were also investigated. They were already implicitly learned by the participants and could therefore either show contextual cueing in pop-out search which could be interpreted as clear counterevidence for the ceiling effect. In the other case they could show no further speeding-up in pop-out search which would be support for the ceiling effect.

### 2.2.2 Materials and Methods

Details were as in Experiment 1a, except for the following changes

*Participants.* Eight (three male, mean age: 27 years) of the 11 students from the first experiment were willing to add a third session within two days.

*Design.* The important change was that repeating configurations that were in the condition pop-out in Experiment 1a were now used in condition serial and the ones in serial were used in pop-out search.

*Instruction.* Instructions were given on the visual search task only. For those participants who were already debriefed after Experiment 1a it was said, that more data were needed from them and that they should focus on the search task.

*Layout of experimental sessions.* One experimental session, which was build up as those in Experiment 1a was conducted. Those participants not debriefed after Experiment 1a were interviewed afterwards this session and asked what they believed was the purpose of the experiment and whether they have noticed configuration repetition.

### 2.2.3 Results

Data were treated as in Experiment 1a. Overall error rate was too low (1.2%) for analysis and thus was not examined.

*Serial search (former pop-out configurations of Experiment 1a):* Mean response times are shown on the right side of figure 2.7. For comparison results from Experiment 1a are also shown. A contextual cueing effect was not present from Epoch 7 on, which was the beginning of Experiment 1b but it evolved as in Experiment 1a. A general speed-up of responses was evident from the beginning and response speed in the first epoch of Experiment 1b started where response speed ended in Epoch 6 of Experiment 1a. An ANOVA with factors Configuration and Epoch showed that both main effects of the factors remained non-significant [Configuration: $F(1,7)=4.49$, $p=0.072$; Epoch $F(2,14)=3.70$, $p=0.053$], in spite of an obvious trend in figure 2.5. Importantly, the interaction between the two factors was significant [$F(2,14)=3.94$, $p=0.044$], which led to the conclusion that contextual cueing was not present from the beginning but developed through training.

*Pop-out search (former serial search configurations of Experiment 1a):* On the right side of figure 2.8 mean RTs are presented. Again no contextual cueing effect was evident in this condition. Speed up of responses was only marginal. An ANOVA with factors Configuration and Epoch showed that both main effects of the factors and their interaction were non-significant [Configuration: $F(1,7)=0.40$, $p=0.846$; Epoch: $F(2,14)=2.60$, $p=0.142$, Configuration x Epoch $F(1,7)=1.183$, $p=0.321$].

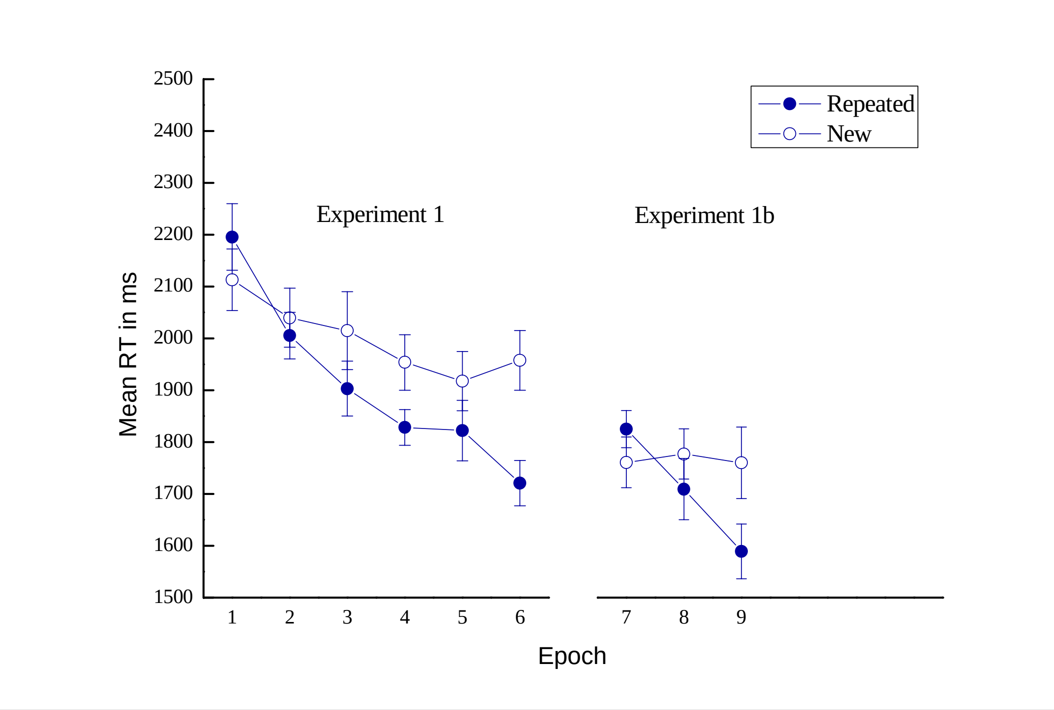


Fig. 2.7: Mean RT in serial search across epochs. The graph on the right shows the results of Experiment 1b with the former repeated pop-out search configurations. For comparison results from serial search in Experiment 1a are shown on the left side.

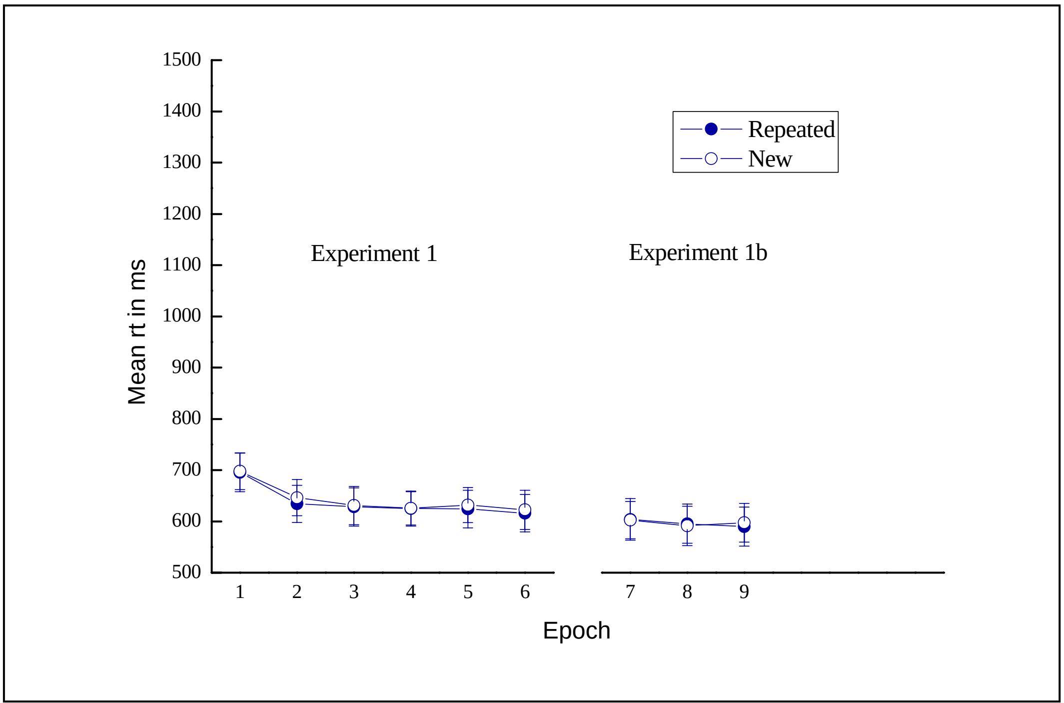


Fig. 2.8: Mean RT in pop-out search across epochs. The graph on the right side shows the results of Experiment 1b with the former repeated serial search configurations.

*Contextual Cueing:* Faster responding to repeated configurations was evident in the serial search condition only. Figure 2.7 suggests that the effects from Experiment 1a and 1b are comparable. In pop-out search the repeated configurations led to no further speed-up, which is support for the ceiling effect hypothesis. Table 2.1 shows the effect for the first three epochs of the serial search condition in both experiments. Thus, it can be concluded that contextual cueing developed the same way in Experiment 1a and 1b. Even the trend that responses to new configurations were faster than responses to repeated configurations that was found in Epoch 1 was evident in Epoch 7.

Tab. 2.1 Shown are RTs as a function of Configuration and Epochs 1-3 in Experiment 1a and 1b. (Standard error in parentheses; t-tests two-tailed, Rep. = Repeated)

| | **Experiment 1a** | | | | **Experiment 1b** | | |
|---|---|---|---|---|---|---|---|
| | **Epoch 1** | **2** | **3** | | **Epoch 7** | **8** | **9** |
| **New** | 2219 (44) | 2060 (48) | 2000 (56) | **New** | 1761 (50) | 1778 (55) | 1758 (70) |
| **Rep.** | 2219 (53) | 2030 (36) | 1907 (44) | **Rep.** | 1825 (42) | 1707 (63) | 1592 (54) |
| **t(10)** | -2.04 | 0.44 | 2.91 | **t(7)** | -1.29 | 1.83 | 2.33 |
| **p** | 0.068 | 0.666 | 0.015 | **p** | 0.237 | 0.110 | 0,050 |

*Evidence for implicitness:* The four participants not debriefed after Experiment 1a were interviewed. None of them guessed the main purpose of the study. One noticed the repetition of a single configuration in the middle of session 2, which he described as conspicuous.

### 2.2.4 Discussion

Experiment 1b brought no support for the assumption that pop-out configurations had been implicitly learned in Experiment 1a. It seems that RTs were already maximally efficient, and participants could not profit from implicitly learning the configurations. For the former pop-out configurations, then used in serial search, the contextual cueing effect evolved as in Experiment 1a, which indicated participants implicitly learned them when they could make use of them. Further support came from the former serial search configurations. Although already implicitly learned in Experiment 1a they did not lead to a contextual cueing effect when used in pop-out search. This confirmed that participants in this task were already at their speed limit. This argument is supported by the finding that the speed-up in pop-out search that was evident in Experiment 1a was absent in Experiment 1b. Importantly, performance of the participants who had been debriefed after Experiment 1a did not differ from those debriefed after Experiment 1b.

To summarize, the results lead to the conclusion that there is no contextual cueing in preattentive search. The strong pop-out effect leads to instant detection of the target stimulus. An analogy can be drawn to the results of Oliva, Wolfe, and Arsenio (2004) described above, who found a strong bias toward performing visual search even in the presence of well-known visual stimuli. When either visual matching or recollection from memory is possible participants made a pragmatic choice between perception and memory. The same could be true for the present results. When pop-out already leads to the fastest response possible then recollection of context information from memory does not seem to be required.

A possible criticism is that because response times in serial search are much longer then in pop-out search, configurations have to be present for a certain amount of time to be implicitly learned. Picture recognition and recall memory improve as presentation duration increases (e.g. Tversky & Sherman, 1975). The mean presentation duration of configurations in the present experiment was different in serial and pop-out search. Contextual cueing might depend on the time available for a certain configuration. This could be investigated by keeping presentation duration constant. However, this possibility can be ruled out, because time alone is not sufficient to produce a contextual cueing effect. Individual differences in RT show that even fast participants produce large contextual effects although they have less time to process configurations. An additional argument comes from Chun and Jiang (1998, Experiment 5) who found contextual cueing effects with displays that were flashed for only 200ms.

## 2.3 Experiment 2

### 2.3.1 Introduction

A question that arises from the results of Experiment 1a is what happens when search efficiency is neither pop-out nor an inefficient serial search but in between? As described above, transition between attentive and preattentive search is not abrupt but can be blurred (e.g. Egeth, Virzi & Gabart, 1984). The aim of Experiment 2 was therefore to investigate conditions with search durations between serial and pop-out search of Experiment 1a. Two conditions were studied, named facilitated serial search (FSS) and slowed pop-out search (SPS).

Another question investigated in this experiment is what happens to the effect if configurations are presented more often? It is possible that the effect evolves further. Maybe at some point participants notice that certain configurations repeat. To lengthen the experiment but to not overextend participants' attention, repeated configurations were shown 45 times in this experiment. Another factor in this experiment was set size, which was varied in two levels. This factor was included to investigate whether larger set sizes increase learning effects because configurations are more detailed or inhibit learning because of longer search durations.

After the search task an explicit recognition test was conducted in the form introduced by Chun and Jiang (1998). Participants were presented two further blocks of repeated configurations mixed with new configurations they had never seen before. The task was to decide whether the configuration presented was repeated or new. If participants cannot decide above chance level which configurations were the repeated ones it can be concluded that learning was implicit. Chun and Jiang (1998) showed that participants were not able to do so after 30 repetitions. The findings could be extended by an investigation after 45 repetitions.

In data analysis it was further investigated whether Simon effects (Simon & Rudell, 1967, Simon, 1969) that might be inherent in the data influence the other effects systematically. The Simon effect refers to the finding that RTs are usually faster when stimulus and response occur at the same relative location than when they do not, even if the stimulus location is irrelevant to the task. For example, participants typically react faster to stimuli that appear on the right hand side on the display if a right button press is required and vice versa for the left side. Explanations of the Simon effect are of two types: those that focus on the spatial nature of the task itself; and those that view the Simon effect as an instance of a more general compatibility phenomenon.

### 2.3.2 Materials and Methods

Details were as in Experiment 1a, except for the following changes

*Participants.* Eight (one male) participants, aged 18-45 years (mean: 25.0), took part in the experiment, either as a course requirement or as volunteers. Vision was normal of corrected-to-normal. None of the participants took part in the former experiment.

*Task.* The task was as in Experiment 1a except for an additional recognition test. The task was to decide whether configurations had been shown before or not. Participants responded by pressing one of the two keys (left → repeated, right → new) on the keyboard.

*Design.* Search type was blocked and varied as an independent variable. Search types FSS and SPS occurred with equal probability. The second independent variable was Configuration, with values Repeated and New. A third variable was Epoch which was repetition of the configurations within the Experiment. Five repetitions were grouped into one epoch. Set size was also varied as another independent factor, with levels nine and 12 stimuli.

The recognition test consisted of two blocks, each containing the 24 repeated configurations repeated in the search task and 24 new configurations. Data were analyzed individually for the two search conditions.

*Material.* Search displays consisted of either nine or 12 squares, each having an interrupted vertical white line on it. The line on the target square was shifted to the left or to the right. Gap size on target and distractors was different (see figure

2.9). In SPS the gap on the distractors was smaller than in FSS leading to a pop-out search that was a little slower and to a facilitated serial search in the other condition.

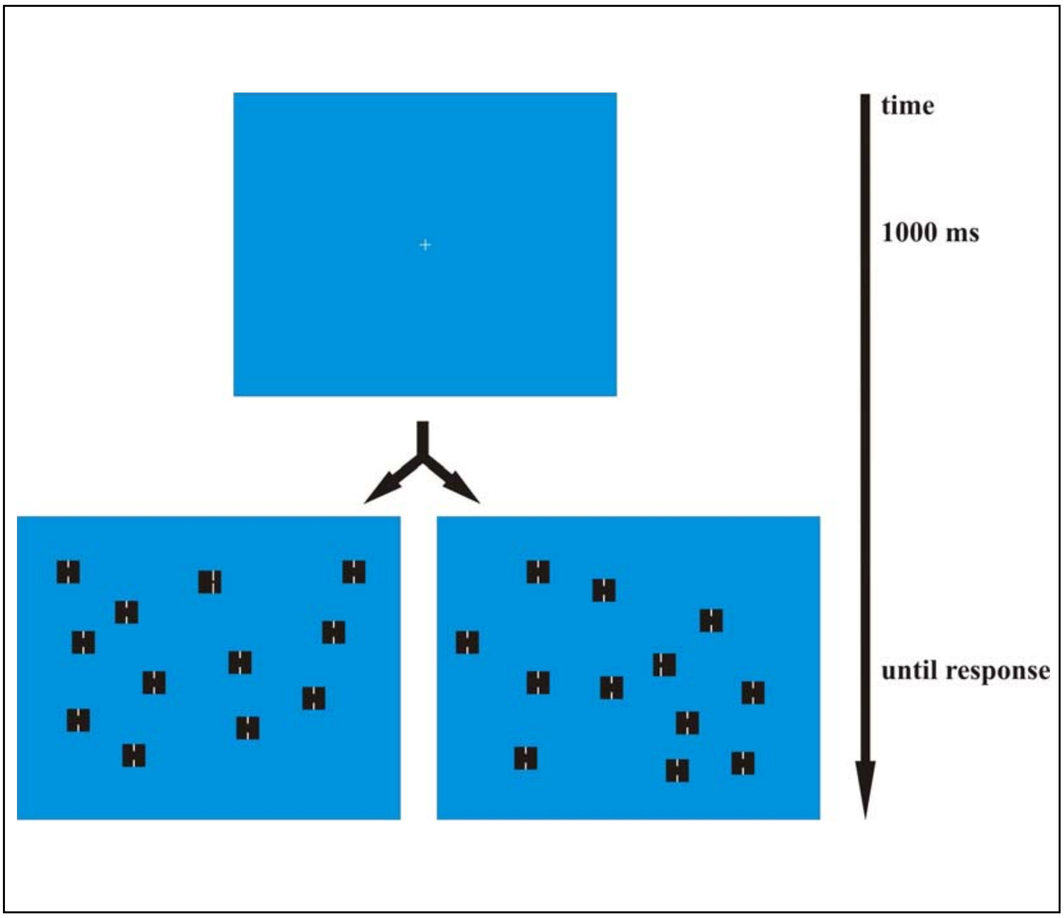


Fig. 2.9: Trial procedure with examples of stimuli used in Experiment 2. Bottom left: slowed pop-out search, bottom right: facilitated serial search

Which configurations were repeated was determined for each participant ahead of the experiment. To control for location probabilities, the target locations of the new configurations were predefined, too.

*Trial procedure.* Trials started with a fixation cross lasting 1s presented in the middle of the monitor display. Next, the search configuration was presented until a response occurred (see figure 2.9).

*Instruction.* Participants were not told about different search types. The task was as in Experiment 1, to find the square on which the line was shifted from the middle. After session 3, the recognition test was explained. Participants were told that accuracy was most important now, while response time was not further recorded. If they were not confident, they were instructed to guess. Importantly, participants had no been told in advance about repetitions or that a recognition test would follow at the end of session 3.

*Layout of experimental sessions.* The experiment was divided in three sessions with the constraint that they had to be completed within three days. Each session consisted of 15 blocks with 48 configurations (24 repeated configurations, 24 new ones) presented in each, leading to a total of 2160 trials. After session 3 participants were asked about the likely purpose of the experiment and whether they had noticed that configurations were repeated. If so, they were asked when and how they realized repetitions and whether they made strategic use of this knowledge. Thereafter the recognition test was conducted.

### 2.3.3 Results

Overall error rate in this experiment was again too low (1.0 %) for an analysis. Set size raised mean RT about 100ms for 12 versus nine stimuli but it did not interact with any other factor of interest (all F´s<1, p´s> 0.50). Therefore, data were pooled across set size.

*Facilitated serial search:* Mean response times are shown in figure 2.10. Participants improved throughout the experiment and shorter RTs to repeated as compared to new configurations are found in later epochs. The ANOVA including factors Configuration and Epoch showed a main effect of Configuration [$F(1,7)=31.07$, $p=0.001$]. General speed-up is reflected in the significant main effect of Epoch [$F(8,56)=21.23$, $p<0.001$]. Although a trend is evident in figure 2.8, the interaction between Configuration and Epoch which would express contextual cueing did not reach significance [$F(8,56)=1.53$, $p=0.17$].

Planned post-hoc comparisons restricted to first, sixth (for comparison with the other experiments) and last epoch demonstrated that repeated and new configurations did not differ from each other in the first epoch [$t(7)=1.20$, $p=0.270$] but repeated were significantly different from new configurations in the sixth [$t(7)=3.66$, $p<0.008$] and in the last epoch [$t(7)=5.00$, $p=0.002$].

*Slowed pop-out search:* Mean response times are shown in figure 2.11. Participants improved throughout the experiment in this condition as well. There seems to be no contextual cueing, but a trend is evident in Epoch 3 shown in figure 2.9. This was confirmed by the ANOVA including factors Configuration and Epoch. The main effect of Configuration did not reach significance [$F(1,7)=0.70$, $p=0.432$]. General speed-up was reflected in the significant main effect of Epoch [$F(8,56)=32.28$, $p<0.001$]. The interaction Configuration x Epoch that would indicate contextual cueing failed to reach significance [$F(8,56)=0.76$, $p=0.641$].

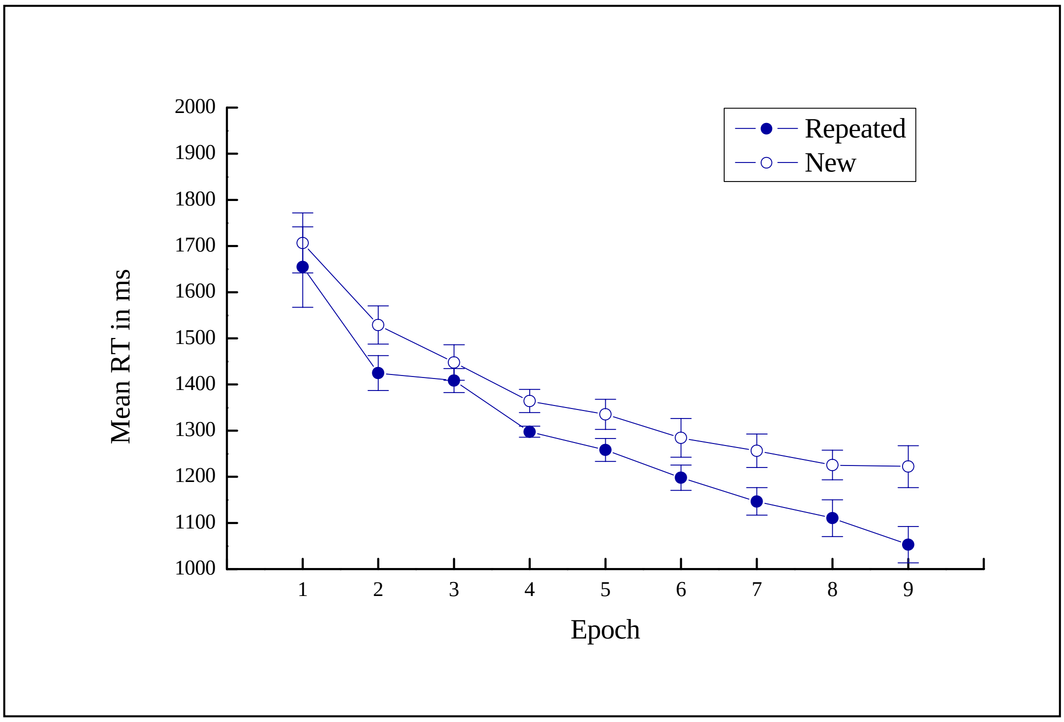


Fig. 2.10: Mean RT in condition facilitated serial search across epochs

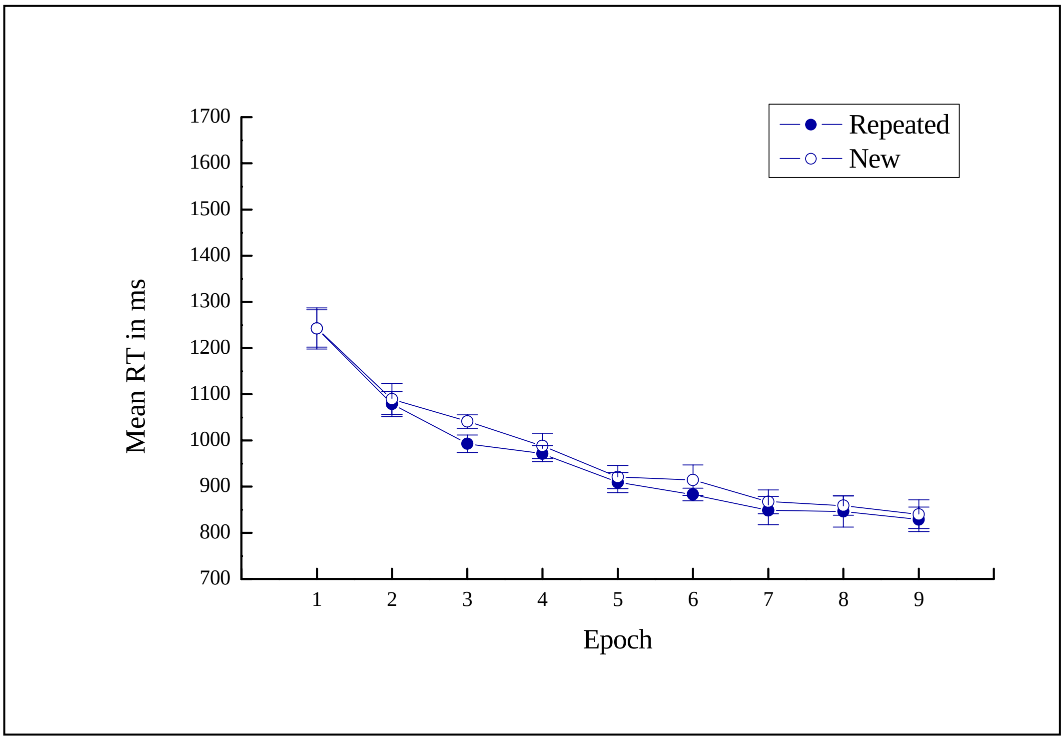


Fig. 2.11: Mean RT in condition slowed pop-out search across epochs

*Contextual Cueing:* For both search conditions the important interaction between Configuration and Epoch failed to reach significance but nonetheless trends are obvious in the data (see also figure 2.12). As can be seen the contextual cueing effect increased over time in FSS but remained almost absent in SPS. For FSS the significant magnitudes of contextual cueing were 77ms in Epochs 4, 5, and 6 [t(7)=4.63, p=0.002] and 131ms in the last three epochs [t(7)=5.27, p=0.001]. For SPS it failed to reach significant difference from 0. It was 20ms in Epoch 4, 5, and 6 [t(7)=0.74, p=0.481] and 14ms in the last three epochs [t(7)=0.66, p=0.533] in this experiment.

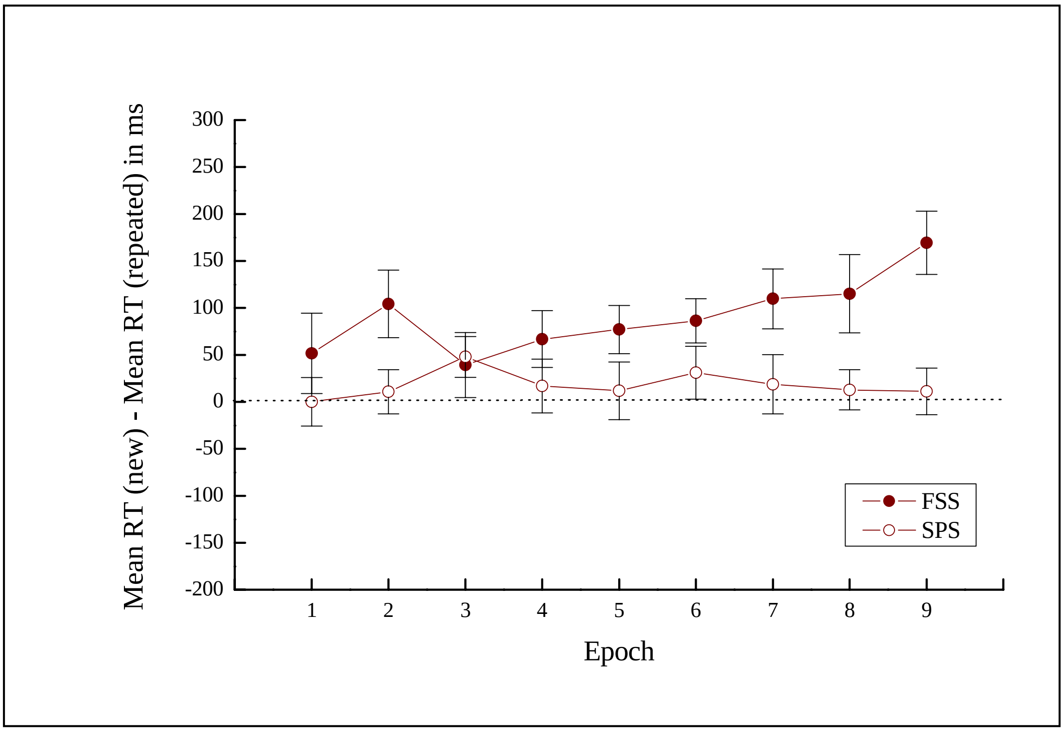


Fig. 2.12: Contextual cueing effect (mean RT for new configurations – mean RT for repeated configurations) across epochs facilitated serial search (FSS) and for slowed pop-out search (SPS)

*Comparison of Experiment 1 and 2:* Mean RTs and the magnitudes of contextual cueing in Experiment 1a and 2 (Epochs 1-6) are shown together in figures 2.13 and 2.14. As can be seen the contextual cueing effect was non-evident in the most efficient search, but arose for more difficult searches. Note that the amount of contextual cueing seemed to increase the longer the search took.

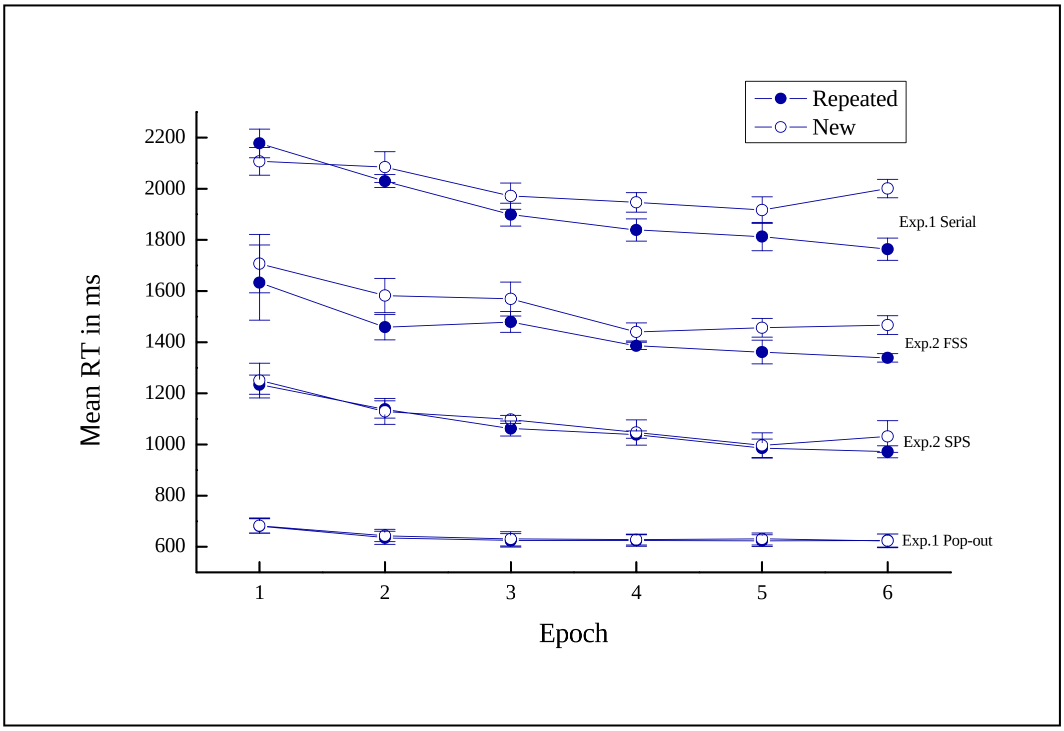


Fig. 2.13: Mean RT in serial and pop-out search across epochs from Experiment 1a and in FSS and SPS in Experiment 2 in Epochs 1-6

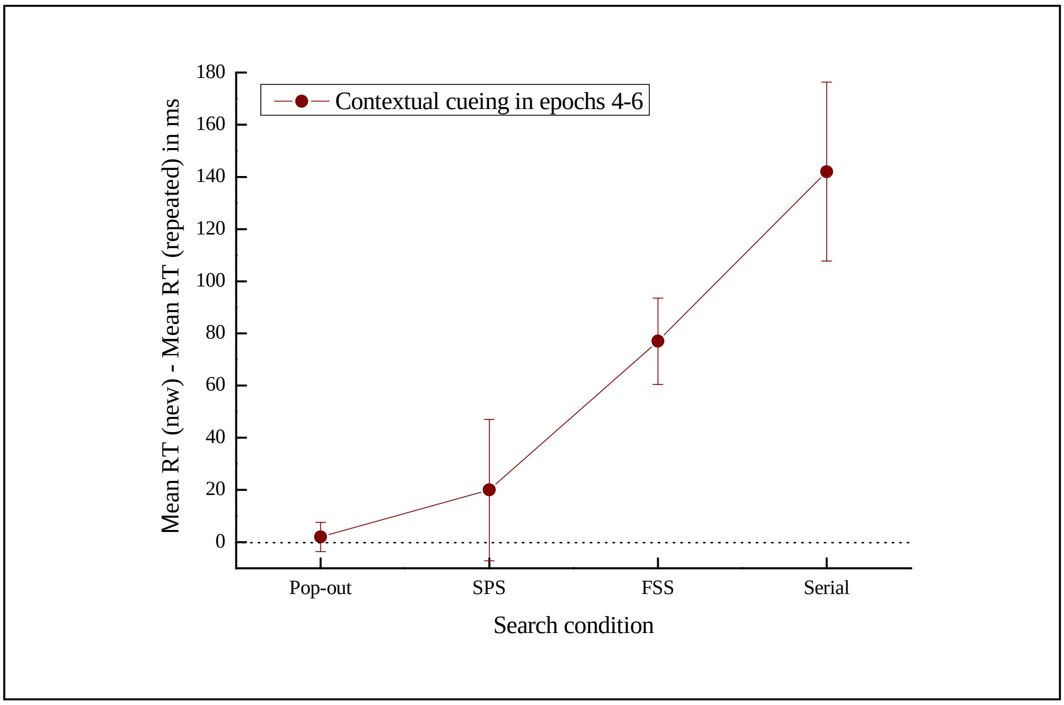


Fig. 2.14: Contextual cueing effect (mean RT for new configurations – mean RT for repeated configurations) in serial and pop-out search from Experiment 1a and FSS and SPS from Experiment 2, containing the effect collapsed across Epochs 4-6.

*Evidence for implicitness:* None of the participants guessed the main purpose of the experiment. Only one participant noticed repetition of configurations. When questioned, she reported that she noticed repetition of a few configurations at the end of session 2 but remained unsure about this. She said that this knowledge had no influence on her further search performance.

*Recognition test:* Note that in the recognition test an improvement in performance was possible in block two, because repeated configurations were seen once more and the focus is already set on the configuration and not on the target any more. Still, two blocks were shown to enhance power of signal detection analysis (Macmillan & Creelman, 1991). Separate analyses for block 1 and block 2 showed that concerns about different results were arbitrary and therefore data were pooled across block as intended. Mean accuracy in the recognition test was 52.1% in FSS and 52.6% in SPS, which corresponds to mean d' values of 0.11 in FSS and 0.14 in SPS. In both conditions, performance was not significantly different from 0 [FSS: $t(7)=0.88$, $p=0.440$; SPS: $t(7)=0.77$, $p=0.466$]. These data can be taken as evidence that participants were unable to discriminate repeated from new configurations.

*Investigation of the Simon effect:* For the analysis, the target location was recorded in each trial and categorized as the three monitor sections left, middle, and right. If there was a Simon effect, responses to the target with a right-shifted line should be the fastest for targets presented on the right side and slowest when presented on the left. Mean RTs for the two target orientations can be seen in figure 2.15. The figure shows that a regular Simon effect was not found. It is obvious that if the target was presented in a middle position it was detected the earliest as can be derived from the shortest RTs. Further, RTs suggest that participants continued the search on the left side and then switched to the right side.

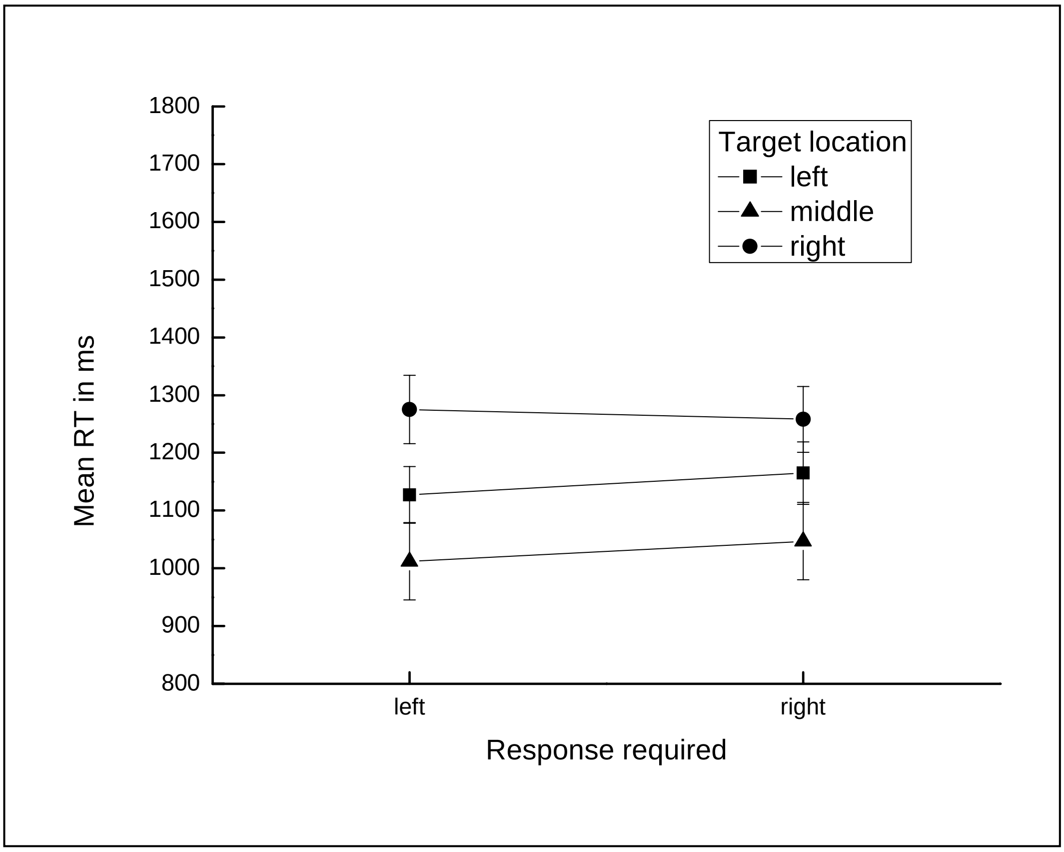


Figure 2.15: Investigation of the Simon-effect: Presented are the mean RTs depending on the target location on the display and the response required.

To investigate the important locations for a Simon effect, target location middle was not included in the statistical analysis. An ANOVA including factors response and location showed a significant main effect of location [F(1,7)=6.20, p=0.042] but not for response [F(1,7)=1.87, p=0,214]. The interaction failed to reach significance [F(1,7)=3.64, p=0.098]. Post-hoc comparisons showed that if the target was presented on the left side and a right button press was required participants reacted slower then if a left button press was required. [t(7)=2.74, p=0.029]. This effect was not found for targets presented on the right side of the display [t(7)=0.93, p=0.385].

### 2.3.4 Discussion

The main finding of this experiment is that the contextual cueing effect evolves along the transition from preattentive to attentive search. There seems to be no abrupt onset of the effect but rather participants learn more, the harder it is to detect the target. Construction of two search types that had search durations in between those of Experiment 1a was successful. In these two search types, participants made use of implicitly learned configurations when the target did not immediately pop-out of the display. Thus, it can be concluded that contextual cueing is modulated by search type: The more difficult the search the larger the effect. It remains open whether this is due to more elaborated learning because of the specific search process. As argued in the discussion of the last experiment, longer configuration exposure by itself cannot account for the effect, because even fast participants produce large effects, too. Inspection of the individual data showed that response speed of the fastest participants in the FSS equaled that of some slower participants in the SPS although their effects have the same size. Another supporting argument already mentioned is that Chun and Jiang (1998, Experiment 5) found contextual cueing effects for briefly flashed configurations.

Noteworthy, the effect still increased after 45 repetitions. It can be speculated that it will increase further after more repetitions. RTs are likely to converge asymptotically to the most efficient RT possible, probably close to the one observed for pop-out search in Experiment 1a.

A remarkable result extends the findings of Chun and Jiang (1998). In the explicit recognition test, participants could not discriminate the repeated configurations better than chance, even after 45 repetitions. This leads to the conclusion that learning effects were indeed implicit. Further, it was assumed in advance that several participants would notice configuration repetition. Astonishingly, only one person realized repetition of the configurations leading to the conclusion that the selected stimulus material is ideal to study implicit context learning. Chun and Jiang (1998) inspected data from participants aware or unaware of configuration repetition and found results did not differ. Since only one participant was aware in this experiment statistical analysis was omitted. Individual data plots showed no conspicuous pattern for this participant. Thus, it is confirmed that contextual cueing is driven by implicit memory representations that were acquired incidentally.

Investigation of the Simon effect showed that such an effect is not present in the data. If the target was presented in a middle position, it was detected the earliest. This was due to presentation of the fixation cross in the middle of the display and verified that participants started to search for the target in the middle as they were instructed to. RTs suggest that, in consistence with reading order, participants continued the search on the left side of the display then switched to the right side when the target was not found at that time. Therefore, the effects influencing RT the most are instruction and reading order. This is not assumed to be a problem since the target locations in repeated and new configurations are chosen randomly and are therefore balanced across conditions.

# 3. Repeating spatial configurations without a fixed target location

## 3.1 Experiment 3

### 3.1.1 Introduction

The aim of Experiment 3 was to replicate a finding of Chun and Jiang (1998, Experiment 3). To distinguish low-level perceptual priming from associative context learning, target locations varied freely across all distractor locations within configurations over repetitions in the experiment. The prediction was that if observers become more efficient in searching through repeated configurations, then a benefit should be obtained for repeated arrays, even if the target appears at various locations. However, if contextual cueing represents associative learning between target locations and contexts, little or no benefit should be obtained for repeating configurations. Chun and Jiang (1998) obtained no contextual cueing effect and concluded that it depends on the association between context items and target location alone. They suggested that observers did not learn to search through repeated configurations more efficiently, but rather learned where a target was most likely to appear given a predictive context.

In this experiment three conditions were contrasted. Conditions Repeated and New were kept from the former experiments. A third condition in which configurations were repeated while the target stimulus varied across all possible distractor locations across repetitions was added. The stimulus material of the serial search condition from Experiment 1a was used.

Variable target locations were expected to not lead to a contextual cueing effect. Further, it was assumed that repeating more configurations in the experiment raises the likelihood of detection of repetition.

### 3.1.2 Materials and Methods

Details were as in Experiment 1a, except for the following changes

*Participants.* Eight students (all female) from the University of Braunschweig, aged 19-34 years, (mean: 24.5 years) took part in the experiment for course credit. They had normal or corrected-to-normal visual acuity. None of the participants took part in one of the former experiments.

*Design.* Configuration was the main independent variable with three factor levels: Repeated target fixed, Repeated target variable, and New. The order of configurations within each block was randomized within blocks. For the data analyses sets of five blocks each were grouped into epochs, yielding six epochs in the entire experiment.

*Material.* Search displays consisted of nine or 12 black squares, each with a vertical white line in the middle. The line on the target square was either shifted to the left or to the right (see figure 3.1).

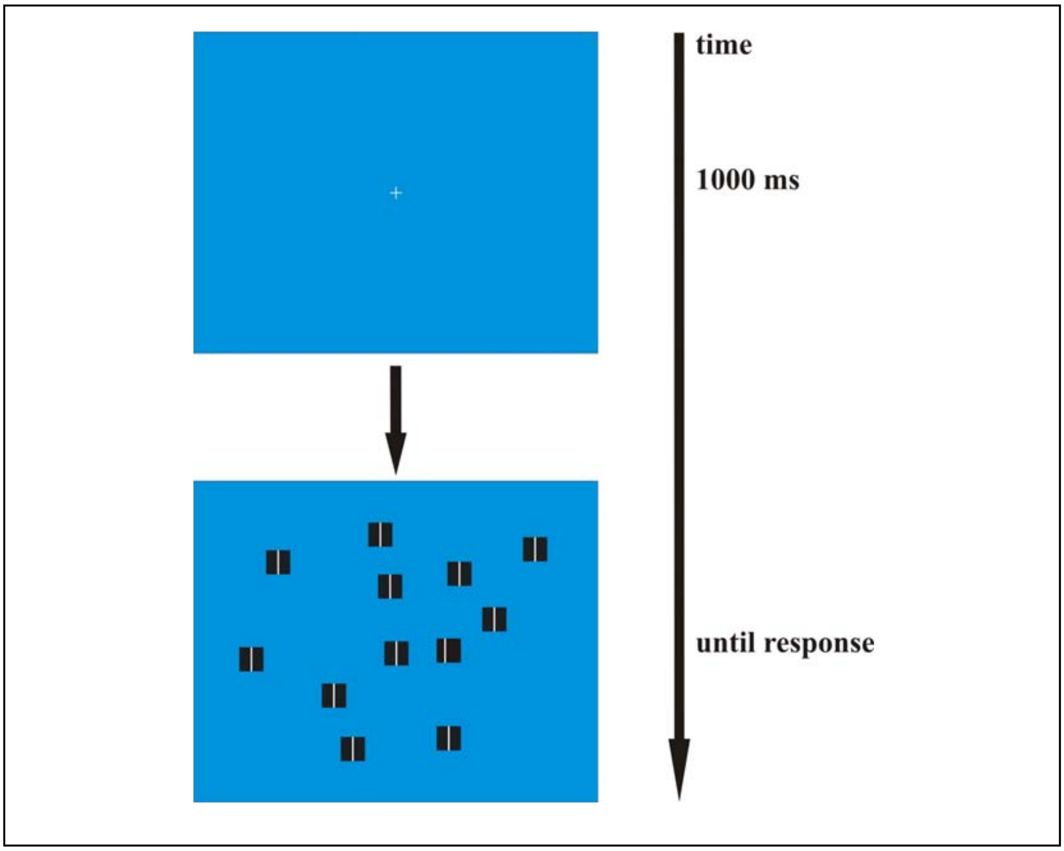


Fig. 3.1: Trial procedure with examples of stimuli used in Experiment 3.

*Layout of experimental sessions.* The experiment was organized in two sessions, which had to be completed within two days. In each block, 16 configurations were newly generated, 16 were repeated configurations with a fixed target, and 16 were repeated with a target at variable locations. Configurations were repeated once every block. Each session consisted of 15 blocks with 48 configurations summing up to a total of 1440 trials.

### 3.1.3 Results

Overall error rate was very low (1.2 %). Set size did not interact with any factor of interest (all F´s<1.79, p´s>0.17). Therefore, data were pooled across this variable.

The mean response times are shown in figure 3.2. A contextual cueing effect was found beginning in Epoch 4, as evidenced by shorter RTs for Repeated target fixed compared with New and Repeated target variable. Participants improved throughout the experiment. An ANOVA including factors Configuration and Epoch showed a significant main effect of Configuration [$F(2,14)=11.34$, $p=0.006$]. General speed-up was reflected in the significant main effect of Epoch [$F(5,35)=24.44$, $p<0.001$]. Contextual cueing was expressed by the significant interaction Configuration x Epoch [$F(10,70)=2.47$, $p=0.013$]. Planned pairwise post-hoc comparisons restricted to first and last epoch were conducted. They demonstrated that New, Repeated target variable and Repeated target fixed did not differ from another in the first epoch, while Repeated target fixed was significantly different from New [$t(7)=3.28$, $p=0.014$] and from Repeated target variable [$t(7)=3.07$, $p=0.018$] in the last epoch.

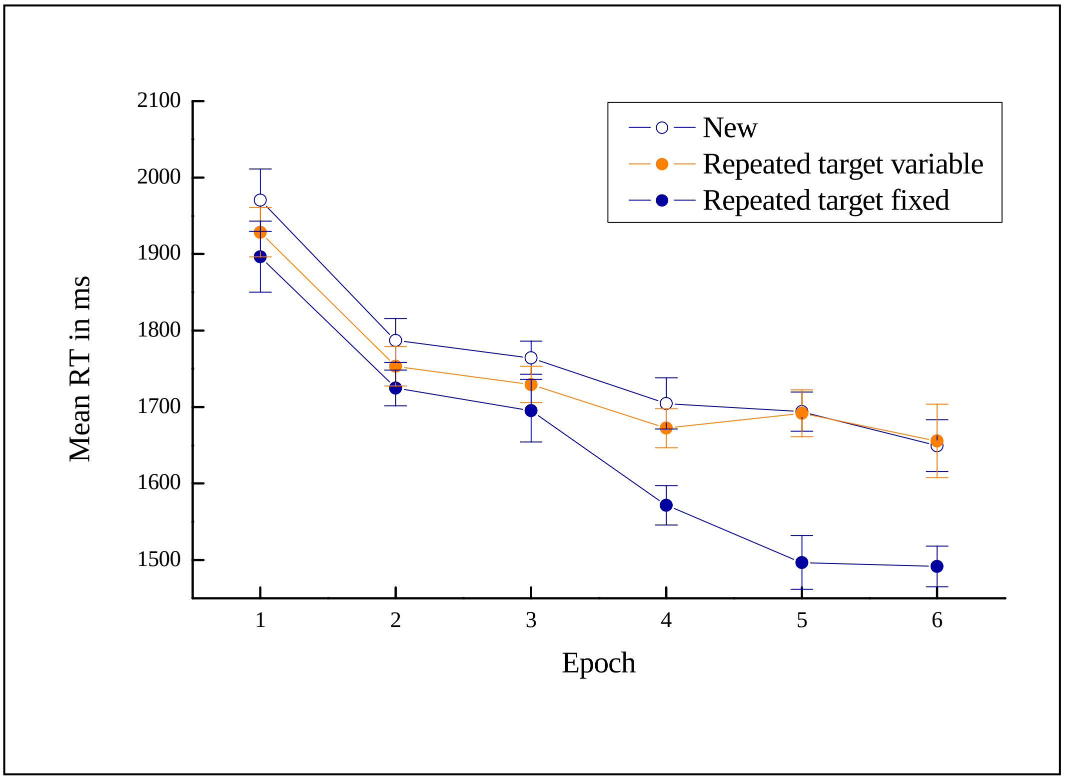


Fig. 3.2: Mean RT in Repeated target fixed, Repeated target variable, and New across epochs

*Contextual Cueing:* The magnitude of contextual cueing was 162ms in the last three epochs for Repeated target fixed [t(7)=4.99, p=0.002], which differed significantly from 0. The magnitude for Repeated target variable [t(7)=0.43, p=0.683] was 8ms, which did not differ.

*Evidence for implicitness:* No participant identified the purpose of the experiment, and none noticed configuration repetition.

### 3.1.4 Discussion

The results of Chun and Jiang (1998) were replicated in this experiment. A response time benefit was found for targets at fixed locations occurring in repeating context compared to configurations that were not repeated. Importantly, no response time benefit was found when the target could appear in all possible distractor locations although the configurations were repeated. Participants could make no use of those configurations and had to search through the configuration as if it was new. Therefore, contextual cueing reflects the association between the fixed target location and the surrounding distractor items.

Note that in repeated and new configurations location probabilities for the target were the same. In the repeated configurations with the fixed target the target was constantly at the same location. In the new configurations the target was also constantly at the same location while distractors were at random locations every trial. When the target varied freely across all possible distractor positions, location probability changed though. However, effects of differing location probabilities do not seem to play a role in contextual cueing since effects were found in Experiment 1 where probabilities differed and in Experiment 2 where they did not.

Importantly, no difference between New and Repeated target variable was found. But the condition Repeated target variable has an interesting advantage compared with the condition New. Configurations are repeated but implicit learning does not occur. A real-world example is the search for a portable office item which is shared with all other colleagues and therefore does not have a regular place where it is usually put in. It does not matter if you search for this item in a foreign or in your own well known office; you have to look in all possible places to find whatever you are looking for.

Since Repeated target variable and New do not differ from another, repeating context with variable target location is used as the baseline in all following experiments. This allows repeating all configurations in the experiment and thus detection of repetition should be increased. This is important because it is investigated in the following experiment whether awareness of repetition influences contextual cueing effects.

# 4. Robustness of implicit learning of spatial context

## 4.1 Experiment 4

### 4.1.1 Introduction

Experiments 1, 2, and 3 already endorsed findings for the robustness of contextual cueing effects against possible changes of the configurations. In these experiments items of the configurations were jittered in the horizontal and vertical direction anew in every trial. Thus, a mechanism in our perception system must exist which allows compensating for these changes and generates one prototypic configuration which is implicitly learned. The aim of Experiment 4 was to investigate this robustness of contextual cueing by manipulating the jitter in the configurations systematically.

Three different jitter levels were constructed. In the first, configurations were jittered just once and remained the same through testing. In the second and third condition, squares were jittered anew every trial, producing a slightly different configuration in every trial. In the second condition, items were jittered up to 19 pixels both in horizontal and vertical direction. In the third condition items were jittered up to 38 pixels, which is the maximum jitter possible without having stimuli touch or overlap. It was expected that when configurations remained the same, the contextual cueing effect is larger then in the conditions where jitter was allowed from trial to trial. Implicit learning effects should be the smallest when squares were jittered up to 38 pixels, since configurations look the most different. This may result in slower or less learning.

A recognition test was introduced which should strengthen the former results of contextual cueing as an implicit effect. Chun and Jiang (1998) and Experiment 2 of this work showed that participants could not distinguish repeated from new configurations. With the intention to improve the sensitivity and validity of the explicit recognition test, to give consideration to the claim of increasing the similarity between the learning task and the recognition test (Reingold and Merikle, 1988, Shanks and St. John, 1994) Chun and Jiang (2003) used a different task.

They presented repeated configurations, with the target substituted by a distractor. The task was to guess the monitor quadrant in which the target would appear. Participants were not able to do so above chance level. Chun and Jiang (2003) argued that this task requires the same type of knowledge that participants benefit from in the search task. However, substituting the target by a distractor changes the configuration immensely. First, the contextual cueing effect depends on implicit learning the location of the target within a certain context and therefore, the target itself is the most important landmark within this configuration. Second, because this test demands a free recall process from the participants it may not activate all the knowledge participants have. Therefore, this test might be too conservative. The test constructed here made use of the fact that recognition performance is usually better than free recall. Two blocks showing only the repeated configurations were used. In one trial of the recognition test, participants were confronted with two versions of one configuration reduced in size. One was the original configuration seen throughout the experiment, the other a fake version in which the target and one distractor item switched locations. The task was to decide whether the left or the right was the original configuration.

The difference to the other tests is therefore, primarily that participants are only confronted with repeated configurations seen 30 times before. The second difference is that the test configuration included the target item which should facilitate the recognition performance. In common with Chun and Jiang (2003) is the fact, that this test also requires the same type of knowledge as required in the search task. Participants have to search for the target first and then make a decision.

### 4.1.2 Materials and methods

Details were as in Experiment 1a, except for the following changes

*Participants.* 10 students (all female) from the University of Braunschweig, aged 19-41 years, (mean: 24.3 years) took part in the experiment for course credit. They had normal or corrected-to-normal visual acuity. None of the participants took part in one of the former experiments.

*Task.* In the recognition test, which followed the search part, the task was to decide whether the configuration presented on the left or on the right was the original version shown in the experiment (see figure 4.1). The original appeared equally often on the left and the right side. Participants responded by pressing two keys on the keyboard.

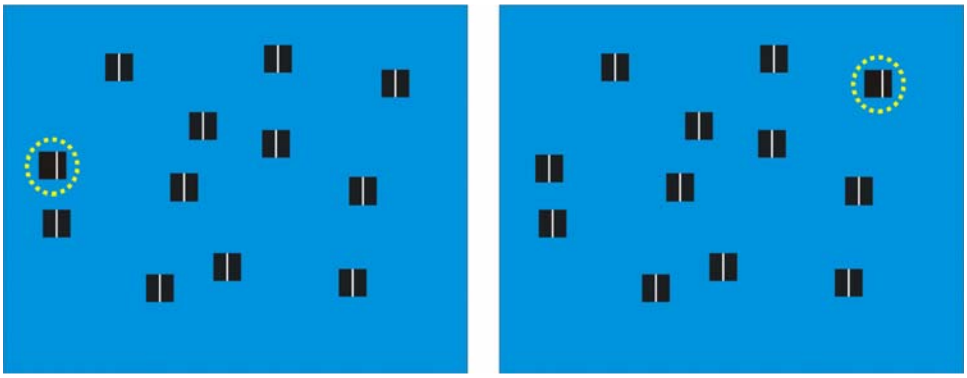

Fig. 4.1: Example of one trial in the recognition test. In either the left or the right configuration the target switched location with one of the distractors. Participants had to decide which configuration was the original one used throughout the search task.

*Design.* Jitter was varied as the main independent variable with the levels No jitter, Small jitter (0-19 pixels), and Large jitter (0-38 pixels). The second variable was Configuration with the factor levels Fixed (repeated configuration with target in fixed location) and Variable (repeated configuration with target in variable location). This factor level was not varied fully. In data analysis Variable was treated as a fourth factor level of factor Jitter.

*Material.* Search displays consisted of 12 black squares. Jitter of configuration was realized with three levels. In the first level, item locations were jittered both in horizontal and vertical direction only once before the experiment by a maximum of 25 pixels and remained that way throughout the experiment. In the second Jitter level, item locations were jittered up to a maximum of 19 pixels anew every trial creating a different configuration in every trial. In the third Jitter level item locations were jittered up to a maximum of 38 pixels.

*Trial procedure.* Remained the same as in Experiment 3.

*Instruction.* After the search task a new instruction was given in which the recognition test was explained. Participants were told that accuracy was important, and response time was not recorded. If they were not confident, they were instructed to guess. Importantly, participants were not told in advance about repetitions, Jitter levels, or that a recognition test would follow at the end of session two.

*Layout of experimental sessions.* The experiment was organized in two sessions. Within each block, 12 configurations were jittered once before the experiment of the type Target variable, 12 configurations also jittered just once of the type Target fixed, 12 configurations jittered up to 19 pixels of the type Target fixed, and 12 configuration with a jitter of up to 38 pixels also of the type Target fixed. Each session consisted of 15 blocks with 48 configurations presented in each, summing up to a total of 1440 trials. The recognition test consisting of two further blocks, containing only the conditions with the fixed target, followed immediately afterwards.

### 4.1.3 Results

Mean response times are shown in figure 4.2. Contextual cueing effects started to appear the latest in Epoch 4. Participants improved throughout the experiment. An ANOVA including factors Jitter and Epoch showed a significant main effect of Jitter [$F(3,27)=12.07$, $p<0.001$]. General speed-up was reflected in the significant main effect of Epoch [$F(5,45)=22.34$, $p<0.001$]. The interaction between factors Jitter and Epoch failed to reach significance [$F(15,135)=1.59$, $p=0.083$], probably due to the expected fanning out of the different Jitter levels in the later epochs. Interaction contrasts for these factors, Epoch and Jitter including first and last epoch also failed to reach significance, which was probably due to the unusual slow RTs in the first epoch of condition Variable. To avoid multiple comparison problems planned pairwise post-hoc comparisons were restricted to the last epoch solely. As seen in figure 4.2 the important comparison, to show Variable differs from the other levels of Fixed, was the one between Variable and Fixed small jitter which reached significance with t(9)=2.24, p=0.050. From this it could be concluded that the other comparisons must reach statistical significance, too. To compare the three Jitter levels of the Fixed condition further t-tests were conducted. None of these comparisons reached significance [Fixed no jitter vs. Fixed small jitter: t(9)=1.48, p=0.173, Fixed no jitter vs. Fixed large jitter t(9)=0.85, p=0.420, Fixed small jitter vs. Fixed large jitter: t(9)=0.67, p=0.518]. Still graphs in figure 4.2 seem orderly arranged from Epoch 3 on.

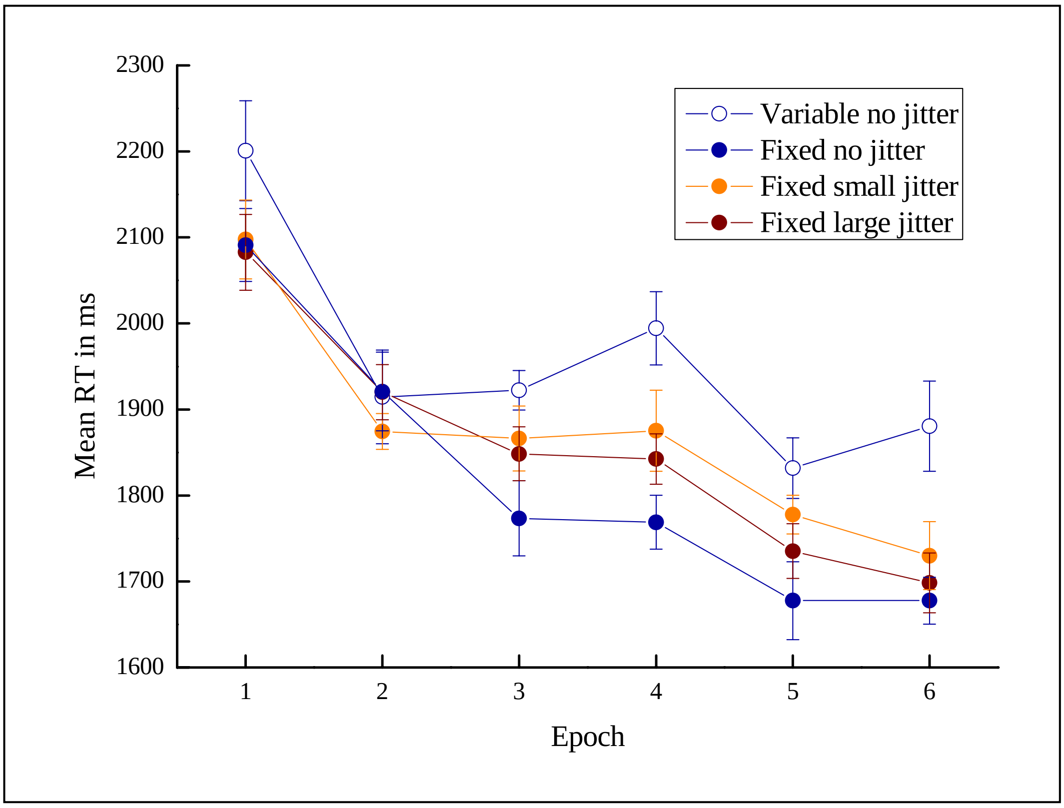


Fig. 4.2: Mean RT in Jitter conditions no jitter, small jitter, and large jitter.

*Contextual Cueing:* The magnitudes of contextual cueing in all conditions differ significantly from 0. For Fixed no jitter the magnitude was 195ms in the last three epochs [t(9)=4.76, p=0.001], 110ms for Fixed small jitter [t(9)=2.83, p=0.020], and 145ms for Fixed large jitter [t(9)=4.73, p=0.001]. ´

*Evidence for implicitness:* None of the participants guessed the purpose of the experiment although two noticed repetition of configurations. Those two participants recognized repetition in the middle of the second session, because of one or two conspicuous configurations. Both participants stated that they did not make any strategic use of the knowledge.

*Recognition test:* Data were pooled across blocks and analyzed separately for Jitter levels. Mean recognition accuracy was 53.3% in Fixed no jitter, 56.3% in Fixed small jitter, and 49.2% in Fixed large jitter. The corresponding mean forced-choice d' values were 0.12, 0.27 and 0.002, respectively. None of these results differed from 0 significantly [Fixed no jitter: $t(9)=0.89$, $p=0.396$, Fixed small jitter: $t(9)=1.63$, $p=0.137$, and Fixed 0-38: $t(9)=0.01$, $p=0.993$]. The d' values are shown in figure 4.3, which includes also the d' values for each individual separately. The results of the two participants aware of configuration repetition did not differ from the other participants´ results. Astonishingly, some participants who seem to be good at recognizing the original configurations in one condition failed to do so in another. This might be due to chance because of low power. Nevertheless, these results can be taken as evidence that participants could not discriminate between the original and the fake configurations. This is further confirmation for an implicit learning process.

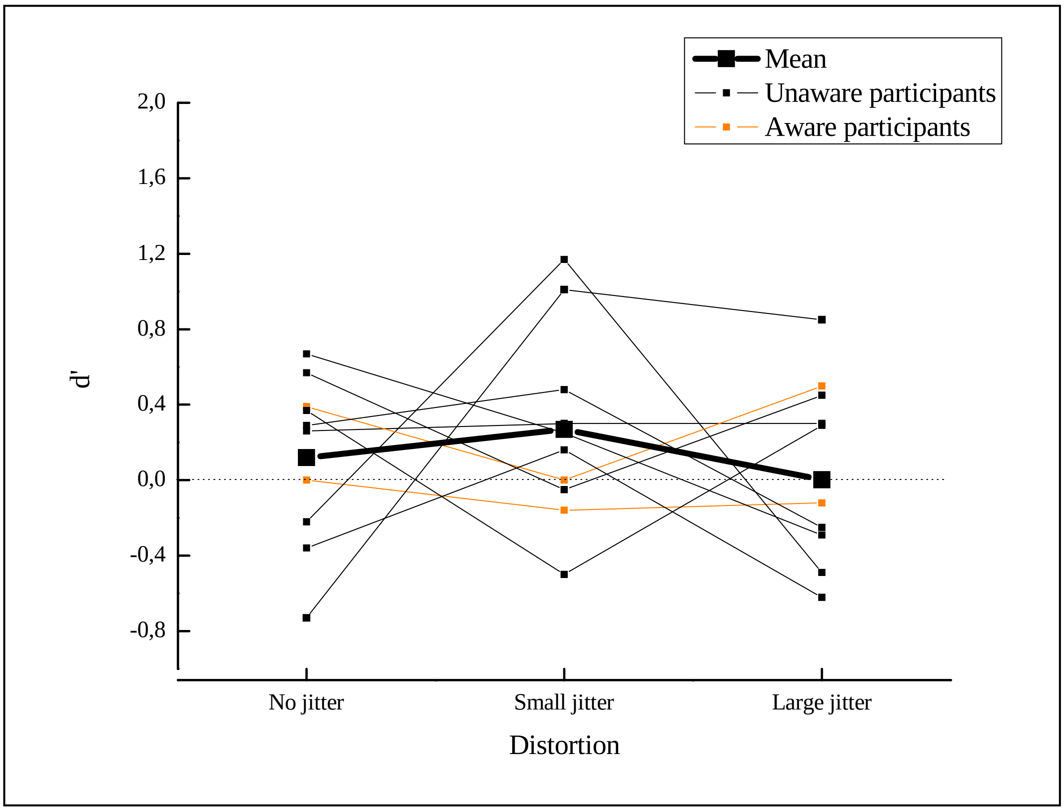


Fig. 4.3: The d' values shown as the mean in the three levels of Jitter, and separately for individuals aware or unaware of configuration repetition.

Comparing the contextual cueing effects for the aware and the unaware group, there does not seem to be a systematic tendency for a greater contextual cueing effect when participants were aware of configuration repetition. The group means are shown in table 4.1.

Tab. 4.1: Magnitudes of contextual cueing effects averaged across Epochs 4-6 in the different levels of Jitter shown separately for participants unaware and aware of configuration repetition, respectively.

| | | Jitter | | |
|---|---|---|---|---|
| | | No jitter | Small jitter | Large Jitter |
| **Awareness of repetition** | Unaware | 187 | 118 | 147 |
| | Aware | 226 | 76 | 138 |

### 4.1.4 Discussion

In this experiment, jitter of the configurations was manipulated systematically in three different levels. When configurations remained the same throughout the experiment, this led to the largest contextual cueing effect. More important, when jitter of each square up to 19 or 38 pixels was allowed, this led to large contextual cueing effects, too. Thus, it can be concluded that contextual cueing effects are robust against jitter of configurations, even if items are jittered to a large extent. This is astonishing, for jitter conditions allowed great shifts for each square and configurations could look very different in every trial. It was expected that larger amounts of jitter would lead to less contextual cueing than smaller amounts, but this was not the case. This could be due to the fact that squares were allowed but not forced to jitter which could result in a shift of only a few pixels. Forcing squares to jitter at least a certain amount of pixels would have probably brought clearer results.

In the recognition test participants were not able to discriminate the original configuration, which they had seen throughout the experiment for many times, from a fake configuration. The introduced recognition procedure did not lead to better performance as compared to the free recall procedure used by Chun and Jiang (2003). Therefore, results give further support for the notion that contextual cueing is an implicit learning effect.

There was no evidence for a greater contextual cueing effect when participants were aware of configuration repetition. Chun and Jiang (1998, Experiments 3, 5) also found that magnitude of contextual cueing does not correlate with awareness of the repetition manipulation.

A problem in the recognition test could be that in the fake configuration the target switched location with a randomly chosen distractor. In some instances, the target could have switched with a distractor right next to it. In other cases, the target switched with a far distractor, e.g. in the opposite corner. If one assumes that far switches lead to better performance than near switches, then test difficulty depends on this target-distractor distance. Since switches are randomly chosen many near switches could therefore lead to a very conservative recognition test. To address this possible problem, the target-distractor distance was investigated in the following experiment.

## 4.2 Experiment 5

### 4.2.1 Introduction

Experiment 5 aimed at the question whether conspicuous configurations, meaning configurations in which the squares are distributed inhomogeneously, are easier to learn or lead to an earlier onset of contextual cueing than configurations in which items are evenly distributed. The idea is that emerging clusters, like rows or columns, might be easier to learn implicitly because of their distinctiveness. Likewise, configurations in which items are distributed homogeneously, which are harder to keep apart from each other because of their similarity could result in smaller effects. Distinctiveness may also result in participants noticing configuration repetition. They might therefore memorize certain configurations. This could lead to better explicit performance in the recognition task, especially for the inhomogeneous configurations.

A further aim of the experiment was to examine the results of the recognition test by investigating the different distances caused by the switch of target and distractor in the fake configurations. The target switched location with a randomly chosen distractor. Thus the target could switch with a distractor right next to it, leading to a very conservative test, for the decision in this trial will be very hard. In the other cases the target could switch location with a distractor far away, which could lead to an easier decision of which configuration is the original one.

### 4.2.2 Materials and methods

Details remained the same as in Experiment 1a, except for the following changes.

*Participants.* 10 students (one male) from the University of Braunschweig, aged 19-42 years, (mean: 26.3 years) were tested in two one hour sessions. All of them took part for course credit. None of the participants took part in one of the former experiments.

*Task.* The recognition task was the same as in Experiment 4.

*Design.* Homogeneity was varied as the main independent factor with the levels Homogeneous and Inhomogeneous. Configuration was varied with the factor levels Fixed (repeated configurations with target in fixed location) and Variable (repeated configurations with target in variable location).

*Material.* Search displays consisted of 12 black squares and were arranged in a 6x8 grid on the displays. Items were jittered up to 25 pixels in vertical and horizontal direction anew in every trial. Homogeneity was realized in two levels. 24 inhomogeneous configurations were created by the restriction that each of these configurations had to include at least one conspicuous item arrangement. This arrangement could be a row or column consisting at least of four aligned squares. This produced highly distinctive configurations with the created alignment and usually several outliers. Homogeneous configurations were constructed by selecting item positions in which the ordinate- and abscissa values were positively (>0.75) ore negatively (<-0.75) correlated. This correlation resulted in a “cloud-like” clustering of the items, allowing almost no distinctive outliers. By itself such a configuration looks distinctive, but 24 of them are indistinguishable. Examples of both conditions are given in figure 4.4.

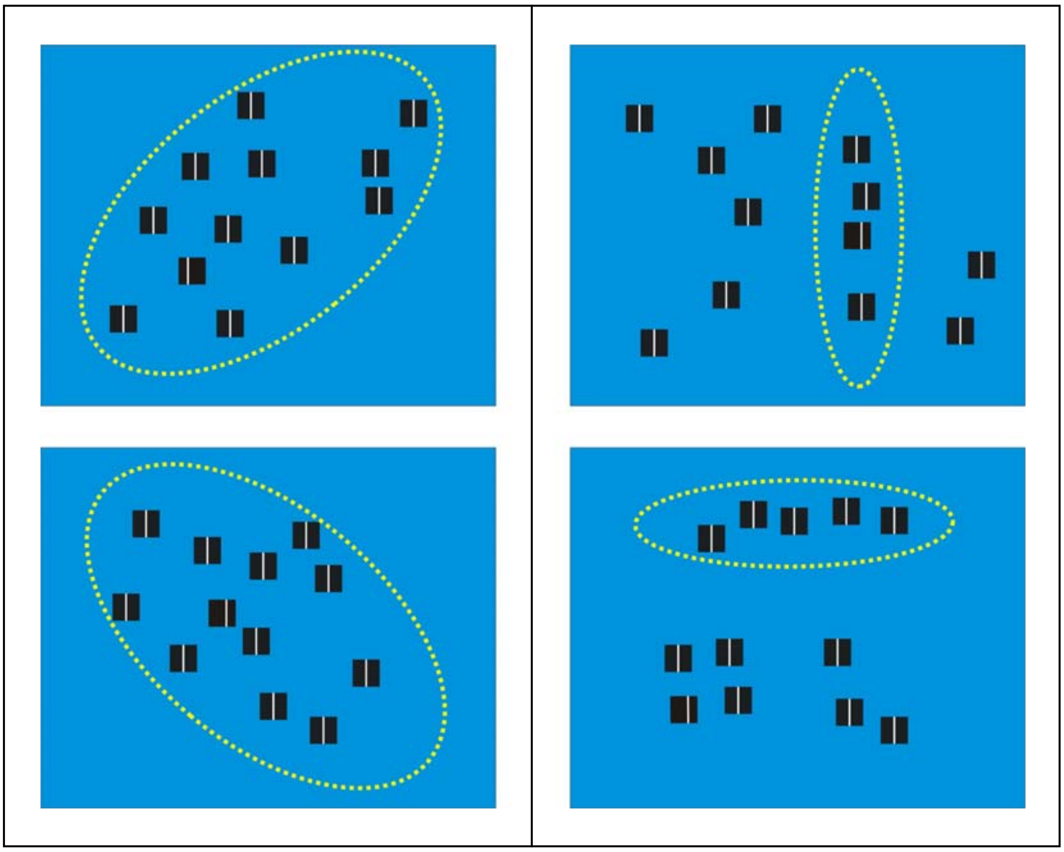

Fig. 4.4: Examples for configurations used in Experiment 5. Item positions in the configurations on the left side correlated with either 0.75 or -0.75 on both axes creating homogeneous "cloudlike" arrangements. On the right side are two examples for the inhomogeneous configurations. In this condition configurations included at least one conspicuous arrangement consisting of either one row or column with a minimum of four items.

*Trial procedure.* It remained the same as in Experiment 4.

*Instruction.* The same instruction as in Experiment 4 was given.

*Layout of experimental sessions.* The experiment consisted of two sessions. Each session contained 15 blocks with 48 configurations, summing up to a total of 1440 trials. The recognition test followed immediately after the search part and contained only the configurations with the fixed target location.

### 4.2.3 Results

Mean response times are shown in figure 4.5. A contextual cueing effect was evident from Epoch 4 on. Participants improved throughout the experiment. An ANOVA including factors Configuration, Homogeneity and Epoch showed a significant main effect of Configuration [$F(1,9)=12.79$, $p=0.006$]. Remarkably, the main effect of Homogeneity remained non-significant [$F(1,9)=0.16$, $p=0.697$]. General speed-up was reflected in the significant main effect of Epoch [$F(5,45)=16.28$, $p<0.001$]. The interaction between Configuration and Epoch reached significance [$F(5,45)=2.71$, $p=0.032$] confirming the contextual cueing effect. As expected, none of the other interactions reached significance. Interaction contrasts for factors Configuration and Epoch including factor levels first and last epoch reached significance [$F(1,9)=7.72$, $p=0.021$], corroborating the finding of contextual cueing.

To compare Homogeneity in both levels of Configuration pairwise t-tests were conducted for the last epoch. Neither the comparison of Homogeneity in Variable [$t(9)=1.06$, $p=0.314$], nor the comparison in Fixed [$t(9)=0.99$, $p=0.350$] reached significance.

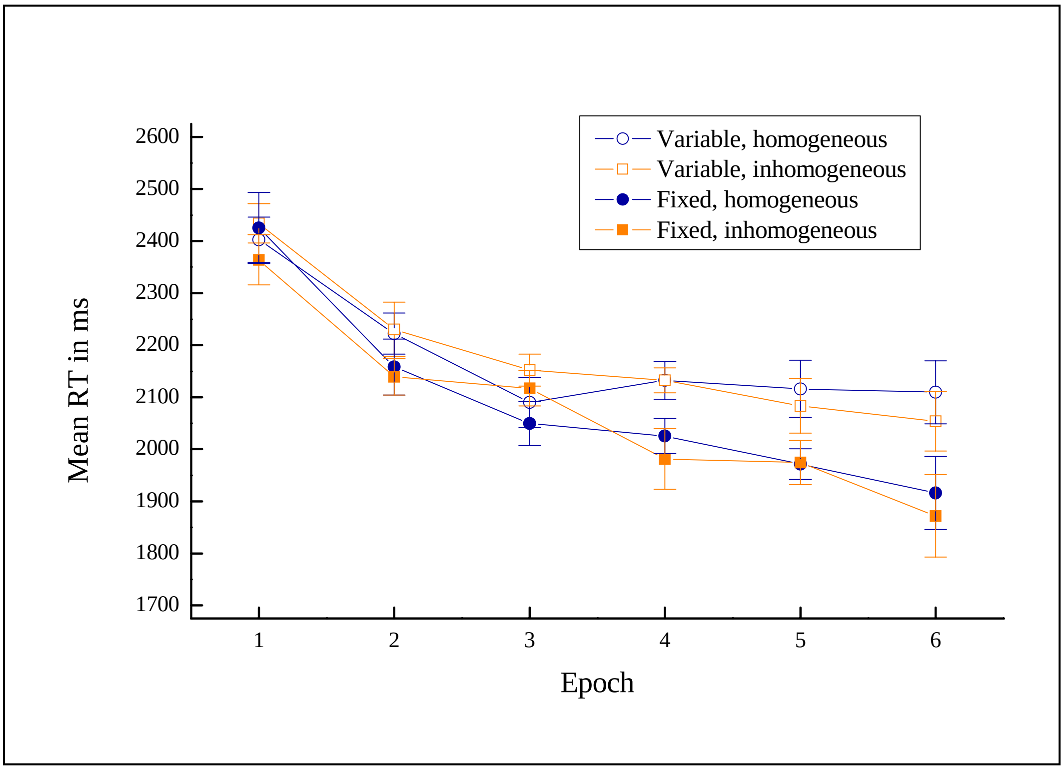


Fig. 4.5: Mean RT for factors Configuration and Homogeneity across epochs.

*Contextual Cueing:* The magnitude of contextual cueing was assessed separately for both levels of Fixed compared to the mean from both levels of Variable. For Fixed homogeneous configurations the magnitude was 133ms in the last three epochs [$t(9)=2.97$, $p=0.016$] and 161ms for inhomogeneous ones [$t(9)=7.32$, $p<0.001$] and both differ significantly from 0.

*Evidence for implicitness:* None of the participants guessed the purpose of the experiment. Noteworthy, four participants noticed configuration repetition. All four noticed repetitions in the beginning or middle of session 2. They all said that some conspicuous configurations with distinctive features were the reason why they noticed repetition. Three of the participants said that they did not make any strategic use of this knowledge. One participant reported checking the outer squares in the configuration first from then on, because she expected the target there more often.

*Recognition test:* Data were pooled across both blocks and analyzed separately for Homogeneity levels. Mean accuracy in the recognition test was 54.2% for homogeneous and 52.5% for inhomogeneous configurations. The corresponding mean d' values for forced choice tasks were 0.17, and -0.06, respectively, which did not reliably differ from 0 [Homogeneous: $t(9)=0.91$, $p=0.389$; Inhomogeneous: $t(9)=0.63$, $p=0.724$]. The d' values are shown in figure 4.6, which includes also the d' values for each individual separately. The results of the four participants aware of configuration repetition did obviously not differ from the other participants´ results. The mean can be interpreted as evidence that participants could not discriminate between the original and the fake configurations.

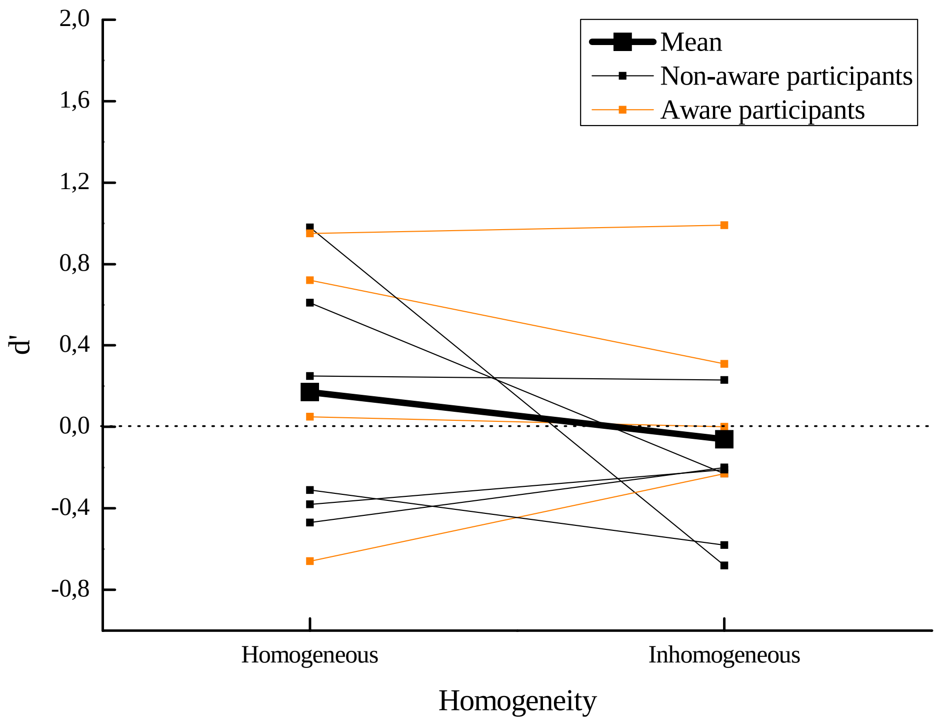


Fig. 4.6: The d' values shown as the mean in Homogeneity, and separately for individuals aware or unaware of configuration repetition.

Contextual cueing effects for aware and unaware participants showed no systematic tendency for effects being greater or smaller when participants were aware of configuration repetition. Means for the different groups are listed in table 4.2. Although the magnitude of contextual cueing for aware participants was low in the homogeneous condition, the contrary pattern was found for unaware participants.

Tab. 4.2: Magnitudes of contextual cueing in ms averaged across Epochs 4-6 in the Homogeneity shown separately for participants unaware and aware of configuration repetition, respectively.

| | | **Homogeneity** | |
|---|---|---|---|
| | | Homogeneous | Inhomogeneous |
| **Awareness of repetition** | Unaware | 171 | 158 |
| | Aware | 76 | 168 |

The same is true when looking at the mean contextual cueing effects of individual participants and their corresponding d’ values (see figure 4.7). No systematic trends were found in the data and it was concluded that contextual effects are not dependent on awareness of configuration repetition or on recognition performance.

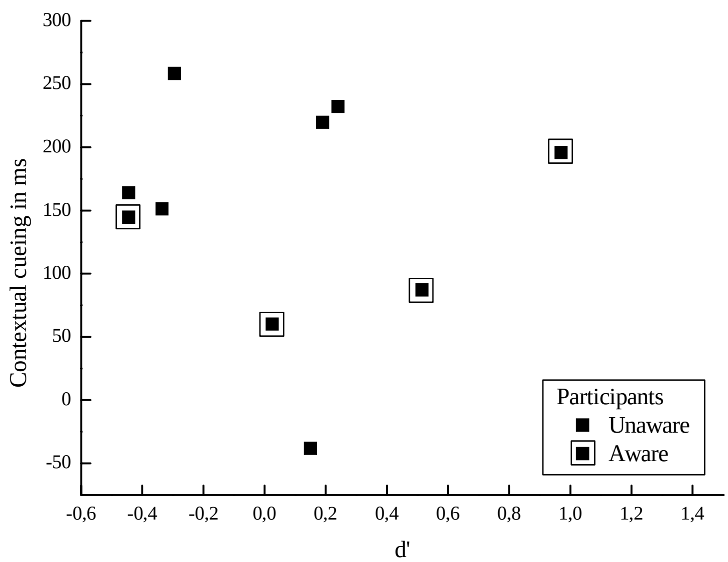


Fig. 4.7: Mean contextual cueing effects for individual participants against their mean d’ values.

Analyzing the data of the recognition test further should give insight whether different distances caused by the switch of target and distractor in the fake configurations can cause performance discrepancies. As seen in figure 4.8 distances were subdivided in two categories (near/far). The red marked cell indicates the location of the target in the original configuration. Switches that fell in the grey shaded area were treated as near, the other switches as far.

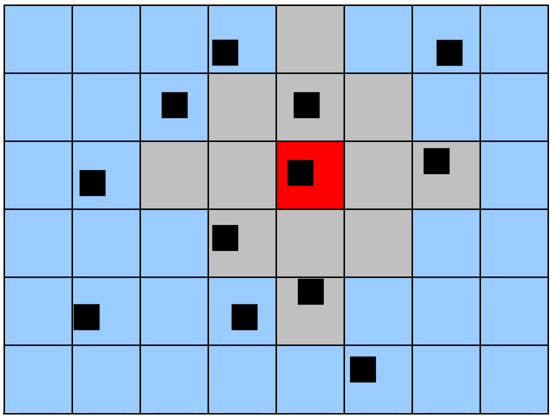

Fig. 4.8: Schematic example for subdividing the display in the two categories near and far. Shown is the 8x6 grid in which squares were allowed to appear. The red marked cell indicates the locations of the target in the original configuration. If the target switched with one distractor in the grey shaded cells it was treated as close in the analysis, otherwise as far.

Reanalyzes of the d' values by taking into account the subdivisions near and far led to the results shown in table 4.3. Even if data are treated with caution for low power reasons, it can be seen that the trend in the data does not favor the hypothesis that performance of participants is better when switches of the target were made with distractors in far locations. Quite the contrary is true. The largest mean d' value was found when recognition was expected to be the most difficult: a homogeneous configuration in which the target switched locations with a near distractor.

Tab. 4.3: Reanalyzed d’ values for homogeneous and inhomogeneous configurations, taking into account categories Near and Far.

| | Homogeneous | Inhomogeneous |
|---|---|---|
| Near | 0.40 | -0.06 |
| Far | -0.02 | 0.13 |

### 4.2.4 Discussion

This experiment investigated whether configurations were easier to learn implicitly that were inhomogeneously distributed. Distinctiveness was expected to result in an earlier onset of contextual cueing or in larger effects. Remarkably, the results indicated that this was not the case. A clear contextual cueing effect was found for homogeneous as for inhomogeneous configurations with no difference between conditions. One might argue that manipulation of homogeneity was ineffective but this was probably not the case. An indicator is that four out of the 10 participants noticed configuration repetition, which is more than in any other experiment before. All four participants reported of conspicuous configurations with clusters of items and distinctive outliers. An analysis of single inhomogeneous configurations would have given further insight but this was impossible due to the experimental set-up, since every participant received a different set of repeating configurations.

Importantly, recognition performance was at chance. Participants failed in the homogeneous as in the inhomogeneous condition to discriminate repeated from fake configurations. Noteworthy, contextual effects do not depend on awareness of configuration repetition or on conscious recognition of configurations. This confirms implicit learning of the configurations.

Furthermore, evaluation of the different distances produced by the switch of the target with a distractor in the fake configuration showed that distance had no effect on performance. If the target switched with a near distractor performance was as poor as if it switched with a distractor in a far location. Data even have a trend in the opposite direction to the hypothesis that homogeneous configurations with a near switch should be recognized the worst.

Thus, it can be concluded that it does not matter for the implicit learning effect whether configurations are homogeneous or not. It seems that distinctiveness raises the likelihood of awareness of repetition, because some configuration pop out of the mass but they are learned equally well as homogeneous configurations.

## 4.3 Experiment 6

### 4.3.1 Introduction

Experiment 6 aimed at the question whether a further attribute that at first glance facilitates implicit learning of the configurations leads to better learning. So far, in the former experiments, responses of participants in the experiments were uncorrelated with the configuration. In other words, participants could never anticipate which key to press, although they had implicitly learned the configuration of target and distractors. This was done because otherwise one could have attributed the learning effect to an associated response, i.e. a simple stimulus-response association. It is assumed that those stimulus-response associations are likely to occur (Chun & Jiang, 1998). This has not been proven and hence is investigated in the following. Participants had to perform the same task as in the experiments before, but in half of the trials an unvaried response was associated with a repeated configuration. It was expected that such configurations are easier to learn and thus lead to larger contextual cueing effects or to an earlier onset of the effect. It is unclear whether an unvaried response will lead to any learning in those configurations that are repeated but in which the target varies across the distractor locations.

A recognition test including fake and original configurations followed the main experiment. It was investigated whether an unvaried response leads to better performance, because of a further attribute which marks the configurations. This could also lead to easier recognition of the configurations.

### 4.3.2 Materials and methods

Details were the same as in Experiment 1a, except for the following changes.

*Participants.* 10 students (one male) from the University of Braunschweig, aged 19-38 years, (mean: 24.6 years) were tested in two one hour sessions. All of them took part for course credit. None of the participants took part in one of the former experiments.

*Task.* The recognition task was the same as in Experiment 4.

*Design.* Response was varied as a main independent variable with the factor levels Unvaried and Varied. Configuration was varied with factor levels Fixed (repeated configuration with target in fixed location) and Variable (repeated configuration with target in variable location).

*Trial procedure.* Trial procedure remained the same as in Experiment 4.

*Instruction.* The same instruction as in Experiment 4 was given.

*Layout of experimental sessions.* Each session contained 15 blocks with 48 configurations, summing up to a total of 1440 trials. 24 configurations were of the type Variable, half of them with unvaried and the other half with varied responses. The other 24 configurations were of the type Fixed with the same splitting in unvaried and varied responses. The recognition test followed immediately afterwards and contained only configurations with the fixed target.

### 4.3.3 Results

Mean response times for Configuration are shown in figure 4.9. For reasons of clarity response times for factor levels of Response are displayed in separate graphs (Figure 4.10 and 4.11). A contextual cueing effect seems to be evident from Epoch 4 on. Participants improved throughout the experiment. An ANOVA including factors Configuration, Response and Epoch showed a significant main effect of Configuration [$F(1,9)=7.09$, $p=0.026$]. The main effect of Response failed to reach significance [$F(1,9)=2.24$, $p=0.168$]. General speed-up of the task is reflected in the significant main effect of Epoch [$F(5,45)=47.44$, $p<0.001$]. The interaction between factors Configuration and Epoch remained non-significant [$F(5,45)=1.32$, $p=0.274$]. None of the other interactions reached significance either. A pairwise post-hoc comparison for the factor Configuration restricted to first and the last epoch reached significance showed Variable and Fixed did not differ in the first [$t(9)=0.88$, $p=0.403$] but in the last epoch [$t(9)=3.57$, $p=0.006$].

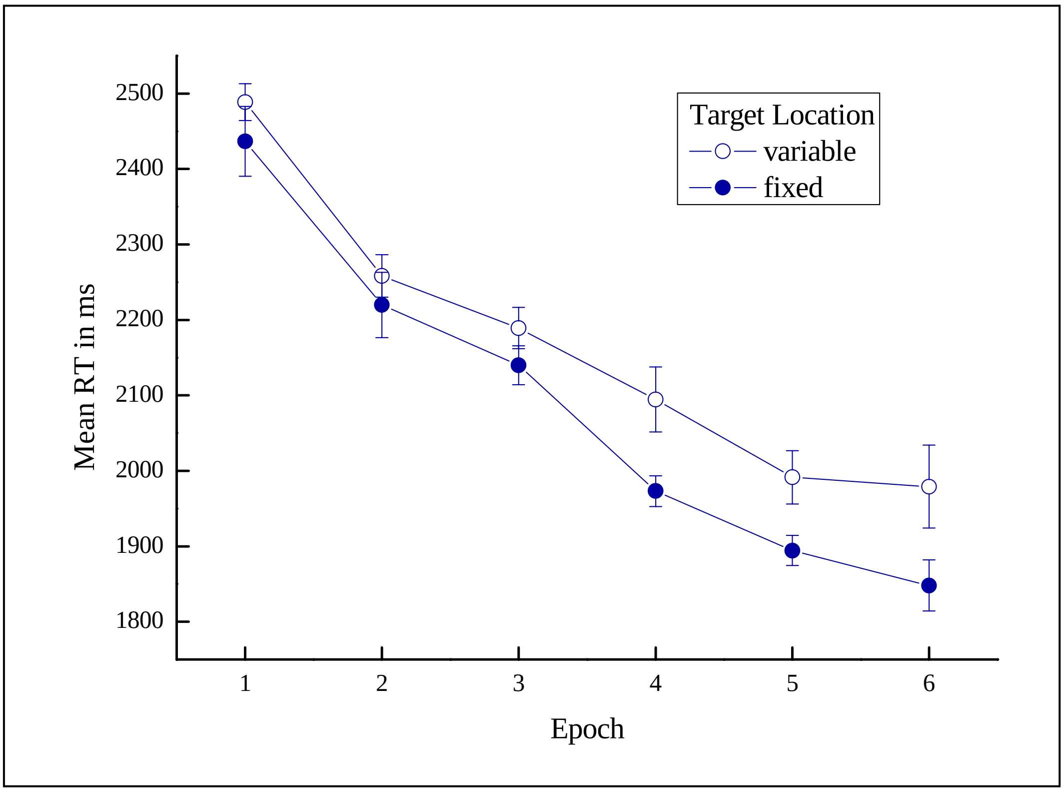


Fig. 4.9: Mean RT for repeated and variable configurations averaged across Response.

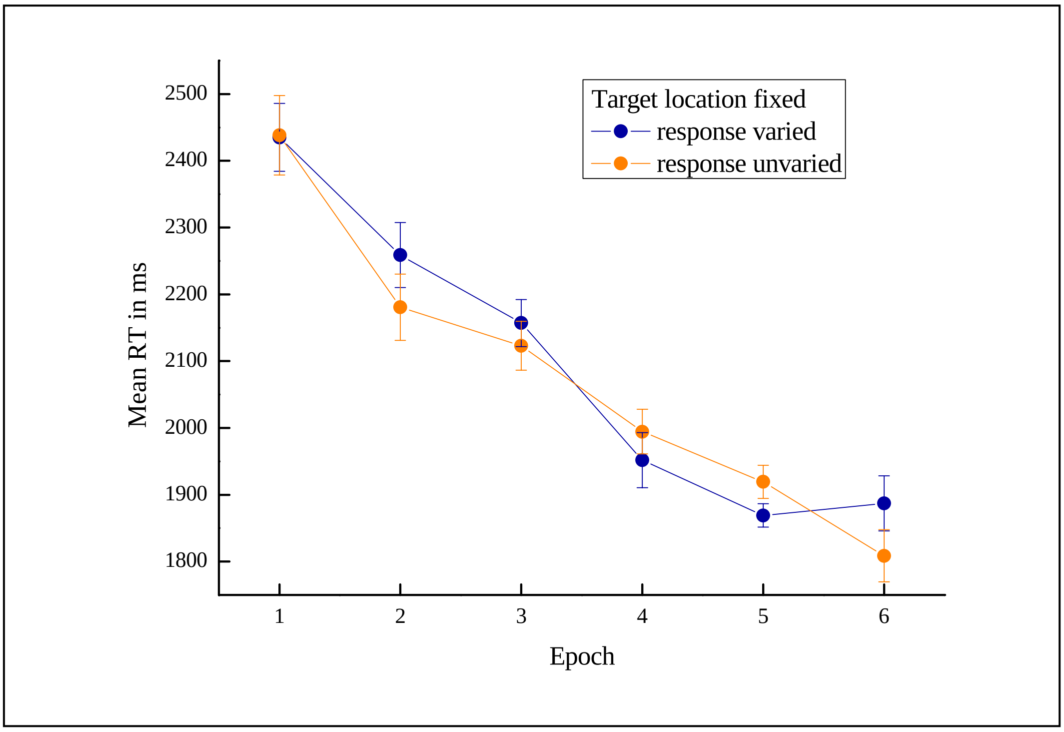


Fig. 4.10: Mean RT for Response in level Target fixed.

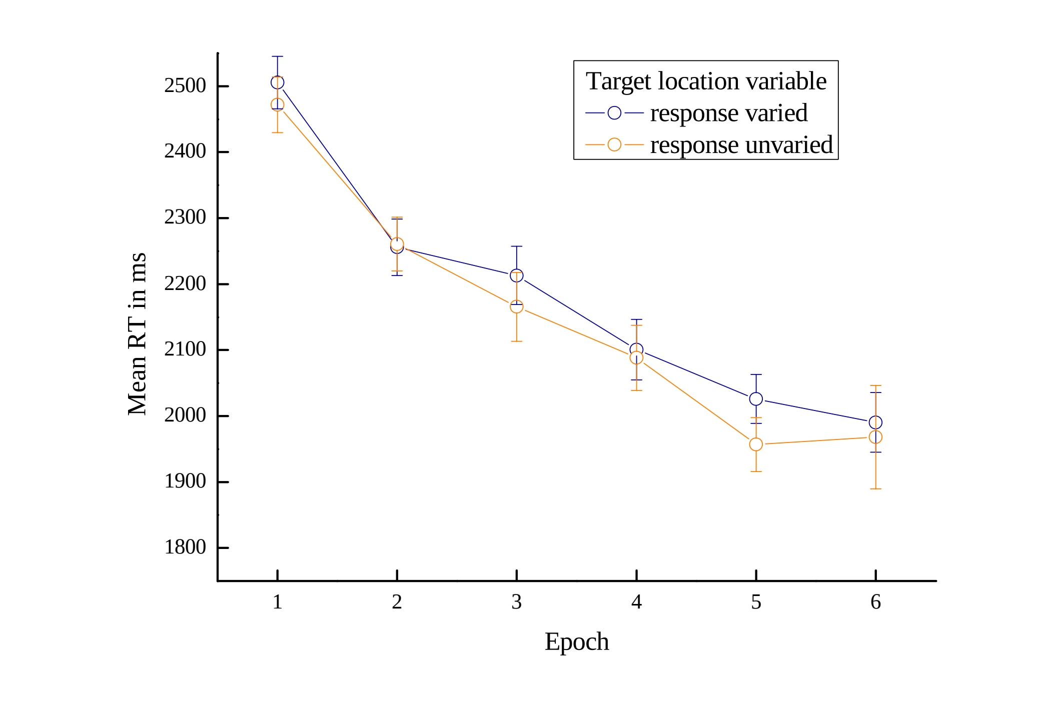


Fig. 4.11: Mean RT for Response in level Target variable.

*Contextual Cueing:* Since the main effect for Response failed to reach significance, data were pooled across this factor and the magnitude of contextual cueing was estimated from factor Configuration solely. Averaged across the last three epochs the magnitude was 116ms which differs significantly from 0 [$t(9)=3.73$, $p=0.005$].

*Evidence for implicitness:* Only one of the participants guessed the purpose of the experiment. When questioned about how she found out, she said that she had heard of the experiments from other students. Four participants noticed configuration repetition, including the one already mentioned.

*Recognition test*: Data were pooled across blocks and analyzed separately for Response levels. Unexpectedly, mean accuracy in the recognition test was 62.1% for repeated configurations with a varied response and 50.8% for those with an unvaried response. The corresponding mean d' values for forced choice tasks were 0.46 and 0.03, respectively. Results differed from 0 in the case of a varied response [$t(9)=3.98$, $p=0.003$] but not in the case of an unvaried response [$t(9)=0.32$, $p=0.755$]. The d' values are shown in figure 4.12, which includes also the d' values for each participant separately. The results of the four participants aware of configuration repetition did not differ from the other participants´ results.

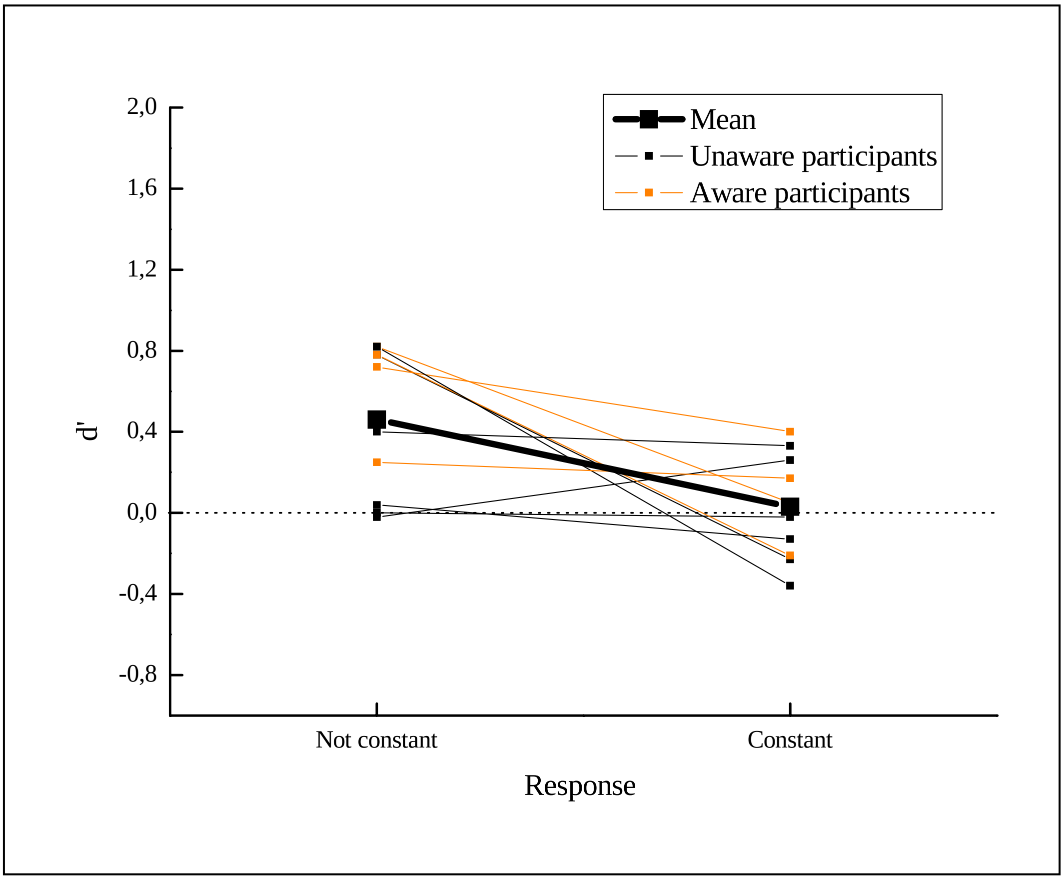


Fig. 4.12: The d' values shown as the mean in Response, and separately for individuals aware or unaware of configuration repetition.

Mean contextual cueing effects for the aware and the unaware participants are shown in table 4.4. Although it seems that awareness of repetition led to a larger contextual cueing effect data must be interpreted in context of the other experiments. There, it was found that awareness of repetition also led to smaller effects. Thus, it can be concluded, that contextual cueing effects do probably not depend on awareness of repetition.

Tab. 4.4: Magnitudes of contextual cueing in ms averaged across Epochs 4-6 in the response conditions shown separately for participants unaware and aware of configuration repetition.

| | | **Contextual cueing** |
|---|---|---|
| **Awareness of repetition** | Unaware | 90 |
| | Aware | 155 |

### 4.3.4 Discussion

In this experiment it was investigated whether configurations with a correlated response would lead to larger contextual cueing effects than those with an uncorrelated response. A stimulus-response association was expected to occur and facilitate implicit learning of the configurations. This should have led to either enhancement of the effect or to an earlier onset. This was not the case; rather, an unvaried response did not lead to any effect. Contextual cueing effects evolved as in former experiments in about Epoch 4 and increased as before. This is a remarkable finding, since it was expected that priming of an associated response is much easier to learn than the complex target-distractor configurations and thus should have led to an enlarged effect.

Results of the recognition test are in line with the fact that an unvaried response did not enhance contextual cueing. Performance was at chance when the response remained unvaried. Unexpectedly, mean performance in the condition with the varied response was slightly above chance, which is puzzling. Nonetheless, implicitness in conditions with varied responses has been proven several times before. The more important result is the one with the unvaried response and it was shown that a possible stimulus-response association did not lead to explicit recognition of the configurations. Some details of the recognitions test in this experiment are maybe criticizable, though. First, when the response was unvaried, targets in the fake configurations were always shown with the original target from the experiment. In other words, when the original configuration included a target which demanded a left response, the same was true for the fake configurations in which the target switched location with a distractor. Open is, whether it may have been easier when targets had been shown the opposite response category in the fake configurations. Second, it is discussible whether the condition Variable with the unvaried response should have been included in the recognition test. It would have been the ideal condition to test recognition of stimulus-response association solely, since a contextual cueing effect does not occur in this condition. But then, this could have led to confusion of the participants, since it would have been impossible to select the original configuration. It would have merely been possible to select the correct response to this configuration.

In sum, unvaried responses did neither lead to enhancement or facilitation of the contextual cueing effect nor to better performance in the recognition task. In these experiments, it does therefore not matter whether the response is correlated with the configuration or not.

# 5. Explicit and implicit learning of spatial context

## 5.1 Experiment 7a

### 5.1.1 Introduction

In the experiments conducted so far, repeated configurations with a fixed target location led to implicit learning effects and configurations could hardly be identified explicitly. In this work and the former experiments by Chun and Jiang (1998, 2003) it did not matter for learning effects to occur whether one was aware of configuration repetition or not. Even if participants were told prior to the experiment that configurations would repeat, it did not lead to different learning effects or better recognition performance in the explicit test (Chun and Jiang, 2003). In this experiment, these findings should be extended by examining whether configurations could be explicitly learned by requesting participants to do so. Therefore, they were told in advance that some configurations would repeat. Those configurations were cued prior to the trial. Participants were instructed, while still responding as quickly and accurately as possible, to memorize cued configurations for these would be tested afterwards. Still, other configurations which were not cued were repeated as well and participants were not told of this. The learning effects for these configurations were compared to the effects of cued configurations. If participants were able to explicitly learn cued configurations learning curves should differ from those of implicitly learned ones.

After the search part the recognition test with the original and the fake configurations followed immediately. It was expected that participants would recognize cued configurations explicitly and that the others which were also repeated remain unrecognized.

### 5.1.2 Materials and methods

Details were the same as in Experiment 1a, except for the following changes.

*Participants.* 10 students (one male) from the University of Braunschweig, aged 20-42 years, (mean: 26.5 years) were tested in a one hour session. All of them took part for course credit. None of the participants took part in one of the former experiments.

*Task.* The main task was now twofold, memorization of the cued configurations and the search for the target stimulus. The recognition task was the same as in Experiment 4.

*Design.* Cue was varied as the main independent variable with the levels Cued and Uncued. Configuration had the levels Fixed (repeated configuration with target in fixed location) and Variable (repeated configuration with target in variable location). Variable configurations were not cued.

*Material.* The cue that marked a repeated configuration which was to be memorized by the participants was a red-colored fixation cross ahead of the trial.

*Trial procedure.* Trials started with a fixation cross lasting 1s presented in the middle position of the monitor. Next, the search display was presented until a response occurred. For details see figure 5.1.

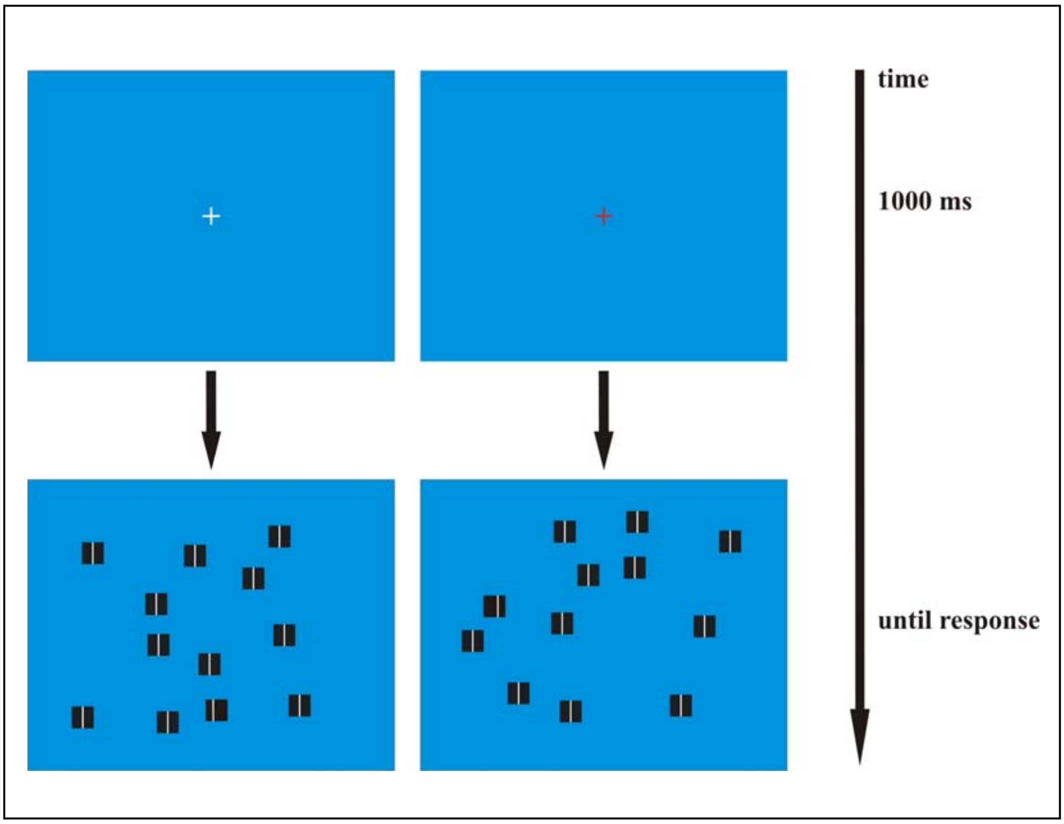


Fig. 5.1: Trial procedure with examples of stimuli used in Experiment 7a. The red fixation cross indicated configurations that were to be memorized.

*Instruction.* Participants were told in advance that cued configurations would repeat. They should try to respond as quickly and accurately as possible and simultaneously try to memorize cued configurations, because these would be tested after the search part. Participants were also instructed not to spend extra time on memorizing configurations.

*Layout of experimental sessions.* The experiment consisted of one session which contained 30 blocks with 24 configurations (=30 repetitions of all configurations), summing up to a total of 720 trials. 12 configurations were of the type Variable. Those configurations were never cued. Six configurations were of the type Fixed provided with a cue in advance of the trial and six further configurations of the type Fixed remained uncued. The recognition test followed after the search task and contained only configurations with the fixed target.

### 5.1.3 Results

Mean response times for cued and uncued fixed configurations compared with baseline configurations of the type Variable are shown in figure 5.2. A contextual cueing effect seemed to be evident very early from Epoch 2 on. Participants improved throughout the experiment. Since the design was nested an ANOVA including factors Configuration and Epoch was conducted and another one including factors Cue and Epoch. The former ANOVA revealed significant main effects of Configuration [$F(1,9)=12.95$, $p=0.006$] and Epoch [$F(5,45)=18.62$, $p<0.001$]. The interaction Configuration x Epoch failed to reach significance [$F(5,45)=0.73$, $p=0.603$], though. The second ANOVA showed that the main effect of Cue did not reach significance [$F(1,9)=0.60$, $p=0.457$]. The main effect of Epoch was confirmed [$F(5,45)=15.84$, $p<0.001$]. The interaction of both factors failed to reach significance [$F(5,45)=1.09$, $p=0.377$]. To compare Fixed with Variable in the first and last epoch planned pairwise post-hoc tests were conducted. Variable configurations did not differ from Fixed uncued [$t(9)=0.86$, $p=0.412$] and Fixed cued [$t(9)=2.19$, $p=0.056$] configurations in the first epoch. As can be seen in figure 5.2 the important comparison to show Variable differs from the Fixed conditions in the last epoch is the one between Variable and Fixed uncued which reached significance [$t(9)=2.25$, $p=0.050$]. From this it could be concluded that the other comparison must reach statistical significance, too.

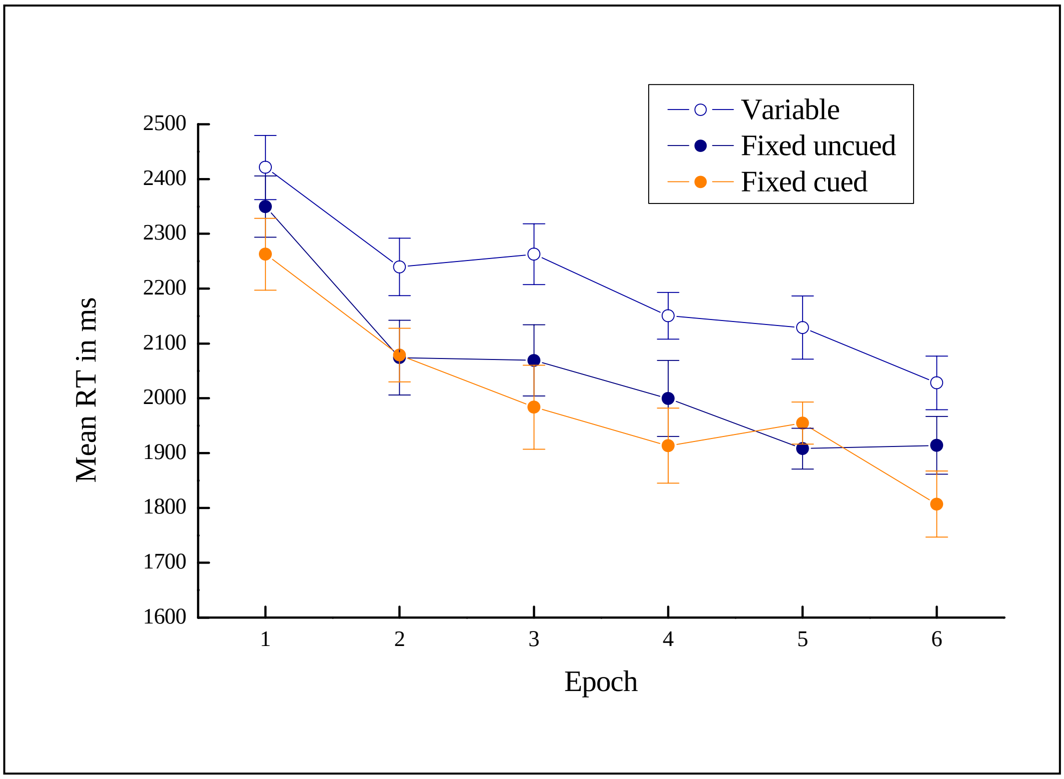


Fig. 5.2: Mean RT for cued and uncued configurations in comparison to condition Variable.

*Contextual Cueing:* Since the main effect of Cue failed to reach significance, data were pooled across this factor and the magnitude of contextual cueing was estimated from Configuration solely. Averaged across the last three epochs the magnitude was 187ms which differed significantly from 0 [t(9)=4.04, p=0.003].

*Evidence for implicitness:* None of the participants guessed the original purpose of the experiment. Two participants noticed repetition of uncued configurations. Both realized repetition almost at the end of the experiment and stated that knowledge had no influence on their further responses.

*Recognition test:* Data were analyzed separately for Cue levels. Mean accuracy in the recognition test was 55.5% for uncued configurations and 60.6% for cued ones. The corresponding mean d' values for forced choice tasks were 0.18 and 0.33, respectively. Those results did neither differ from 0 significantly in the case of uncued configurations [t(9)=0.88, p=0.404] nor in the case of those that were cued [t(9)=1.71, p=0.121]. The mean d' values are shown in figure 5.3, which includes also the d' values for each participant separately. As can be derived the results of the two participants aware of configuration repetition did not differ from the other participants´ results.

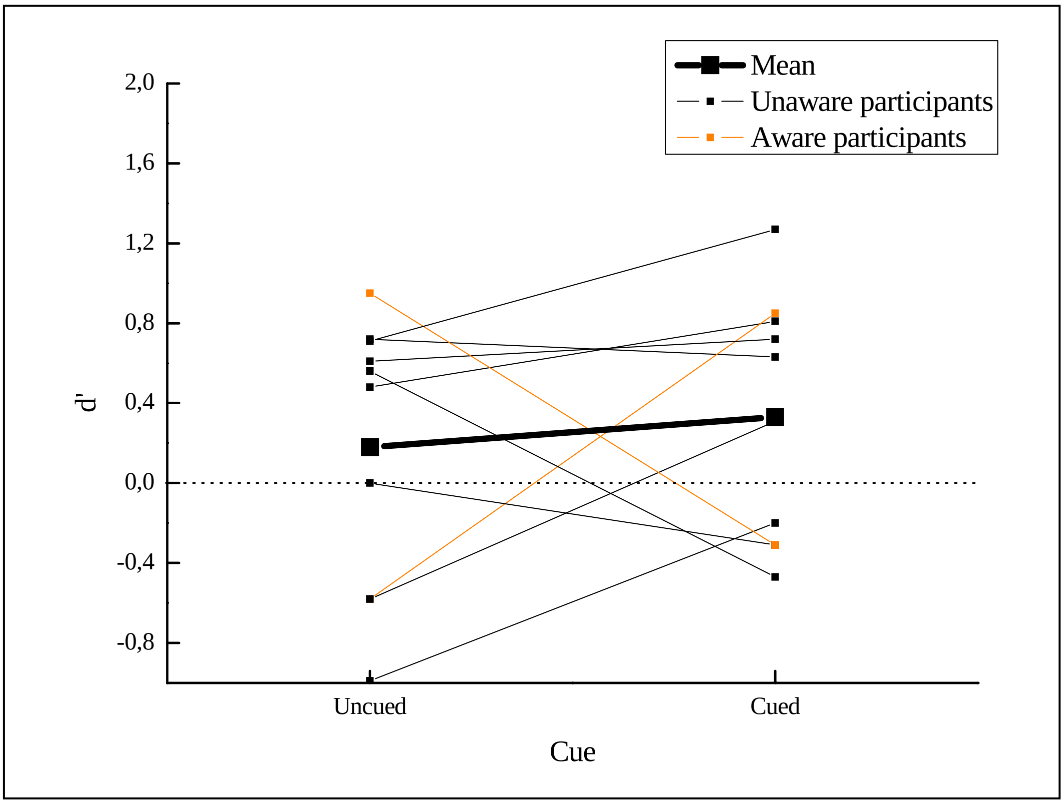


Fig. 5.3: The d' values shown as the mean in Cue, and separately for individuals aware or unaware of configuration repetition.

### 5.1.4 Discussion

Experiment 7a investigated whether participants were able to explicitly learn configurations and whether learning effects of these configurations differed to those of implicitly learned ones. Although only six configurations had to be memorized participants were hardly able to do so. This might be the reason why contextual cueing effects were the same. An almost significant difference between cued and baseline configurations in the first epoch suggests that configurations were different from the start. This may have led to the non-significance of the important interaction that would indicate contextual cueing.

There is only a trend in the recognition test data showing participants recognized cued configurations better than the others. This could be due to several reasons.

First, six configurations that do not differ much from other configurations could be too many to be memorized after only 30 repetitions while the main focus is on another task. Second, conflicting instructions could have made it impossible to memorize configurations. Participants were instructed to respond as accurately and as quickly as possible to the search task and simultaneously memorize cued configurations. It is possible that participants were not able to follow the instruction and simply focused on the main task. Evidence for this can be found in the mean RT which did not differ from mean RT in the other experiments. Finally, maybe participants were able to memorize configurations as a whole but failed to memorize the location of the target and therefore the used recognition test was not sensitive to their knowledge. However, this possibility seems unlikely, since the location of the target is always the main focus of configurations and if these were learned than this location should be remembered the best. No hint is also found in contextual cueing data. Cued and uncued configurations led to same contextual cueing magnitudes. The following experiment tried to rule out some of the mentioned objections.

## 5.2 Experiment 7b

### 5.2.1 Introduction

This experiment also investigated whether configurations can be explicitly learned and whether this leads to different learning curves compared to the implicitly learned configurations. One problem in the last experiment was conflicting instructions. Participants were requested to respond as quickly and accurately as possible to the search task and at the same time to memorize cued configurations. It was asked not to spend extra time on this process and this may have led to the problem that participants were not able to adequately follow the instruction. To test this hypothesis and avoid this problem, the experimental set-up used here, allowed participants to spend extra-time on the memorization process. This was realized by presenting configurations without the vertical white lines first and then lines were added. This ensured that participants could focus on memorization, because they were not able to react to the search task. After lines were added, participants could respond. In this way, instructions did not conflict anymore. But this set-up bared another risk, because repetition of uncued configurations that should remain unnoticed was more likely to be detected.

After the search part the recognition test with the original and the fake configurations was conducted. This should give information on whether cued configurations could be recognized explicitly and whether the uncued ones remained implicit.

### 5.2.2 Materials and methods

Details remained the same as in Experiment 7a, except for the following changes.

*Participants.* 10 students (three male) from the University of Braunschweig, aged 18-45 years, (mean: 24.3 years) were tested in a one hour session. All of them took part for course credit. None of the participants took part in one of the former experiments.

*Task.* The main task was again twofold but was to be performed one after the other. After presentation of a red fixation cross, the configuration shown was to be memorized, in the case of a white fixation cross there was no task. When vertical lines appeared, the task was the search for the target stimulus within the display.

*Trial procedure.* Trials started with a fixation cross lasting 700ms presented in the middle position of the monitor. Next, the configuration was presented without the white vertical lines for 1200ms. Then vertical lines were added and the display remained until a response occurred. For details see figure 5.4.

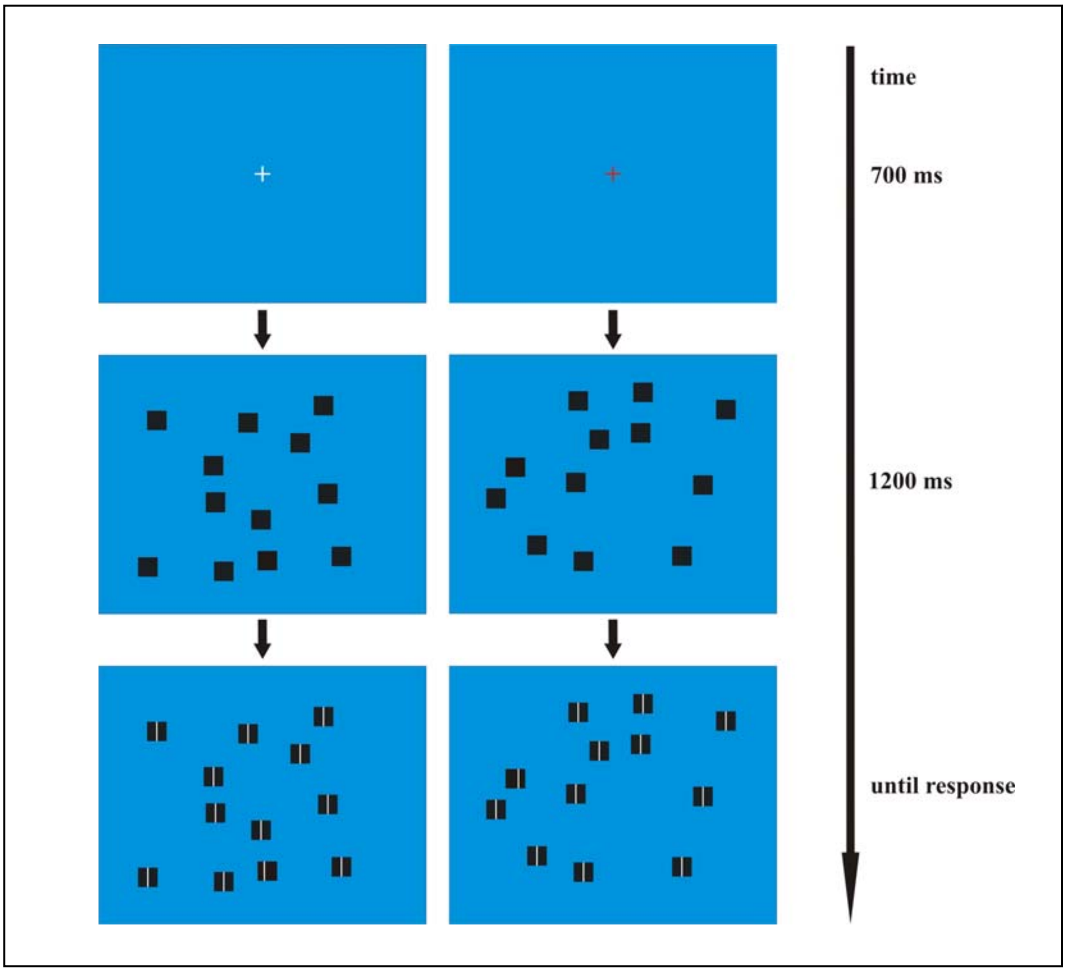


Fig. 5.4: Trial procedure with examples of stimuli used in Experiment 7b. The red fixation cross indicated configurations that would repeat and which should be memorized.

*Instruction.* Participants were told in advance that cued configurations would repeat. They were instructed to memorize those in the phase where configurations were presented without the vertical lines. It was told these configurations would be tested after the main experiment, but then with vertical lines. There was no special instruction for uncued configurations. After the vertical lines were added, participants should try to respond as quickly and accurately as possible to the search task.

### 5.2.3 Results

Mean response times for cued and uncued fixed configurations compared with baseline configurations of the type Variable are shown in figure 5.5. A contextual cueing effect was found from Epoch 3 on. Participants improved throughout the experiment. Since the design was nested an ANOVA including factors Configuration and Epoch was conducted and another one including factors Cue and Epoch. The former ANOVA revealed significant main effects of Configuration [$F(1,9)=26.08$, $p=0.001$] and Epoch [$F(5,45)=18.62$, $p<0.001$]. The interaction Configuration x Epoch reached significance [$F(5,45)=7.16$, $p=0.003$]. Likewise did the interaction contrast restricted to first and last epoch [$F(1,9)=23.83$, $p=0.001$] The second ANOVA showed that the main effect of Cue did not reach significance [$F(1,9)=0.67$, $p=0.801$]. The main effect of Epoch was confirmed [$F(5,45)=20.27$, $p<0.001$]. Importantly, the interaction of both factors reached significance [$F(5,45)=3.82$, $p=0.018$]. Post-hoc tests revealed significant interaction contrasts for the fifth [$F(1,9)=10.27$, $p=0.011$] and sixth [$F(1,9)=7.47$, $p=0.023$] epoch.

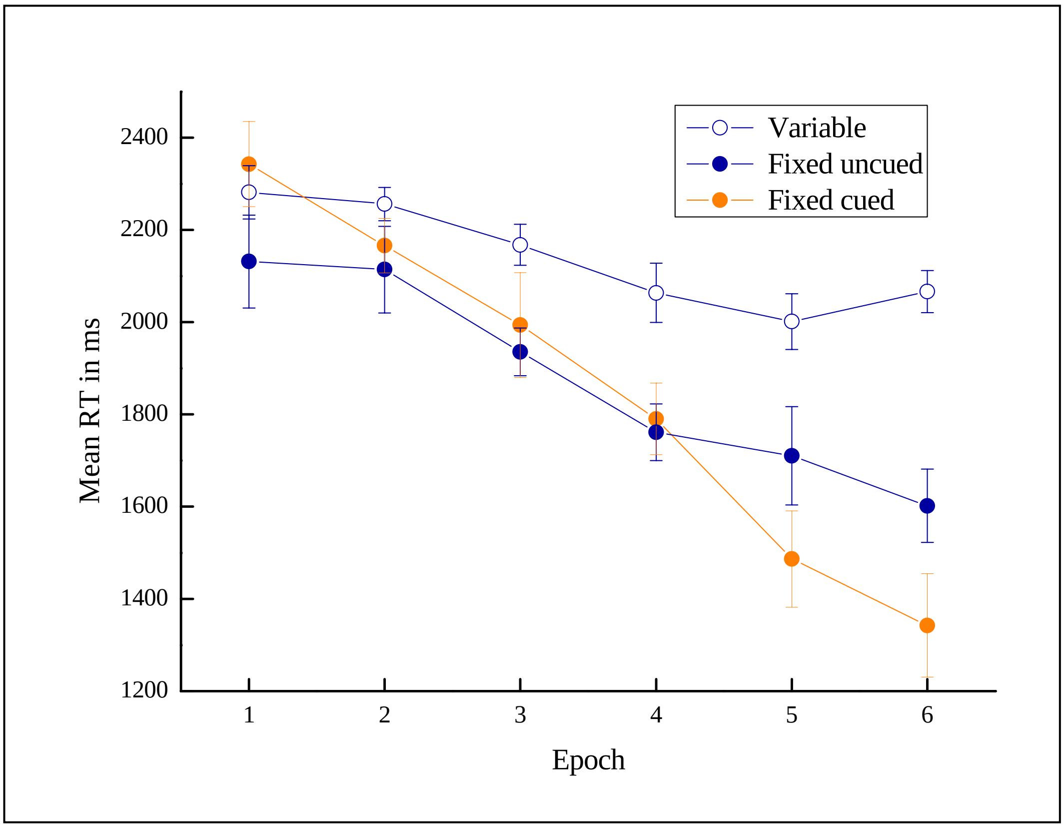


Fig. 5.5: Mean RT for cued and uncued configurations in comparison to condition Variable.

*Contextual Cueing:* The magnitude was estimated separately for both levels of Cue against the mean of Variable. For uncued configurations the magnitude was 352ms in the last three epochs [t(9)=3.38, p=0.008] and 505ms for cued ones [t(9)=4.77, p=0.001]. Both magnitudes differed significantly from 0.

*Evidence for implicitness:* None of the participants guessed the original purpose of the experiment. As expected, more participants noticed repetition of the uncued configurations this time. In this case, it was six participants. Four of them noticed repetition close to the end of the experiment and two noticed it in the middle.

*Recognition test:* Data were analyzed separately for Cue levels. Mean accuracy in the recognition test was 56.6% for uncued configurations and 68.2% for cued ones. The corresponding mean d’ values for forced choice tasks were 0.24 and 0.65, respectively. Those results did not differ from 0 significantly in the case of uncued configurations [t(9)=0.95, p=0.367] but in the case of those that were cued [t(9)=3.89, p=0.004]. The mean d’ values are shown in figure 5.6, which includes also the d’ values for each participant separately.

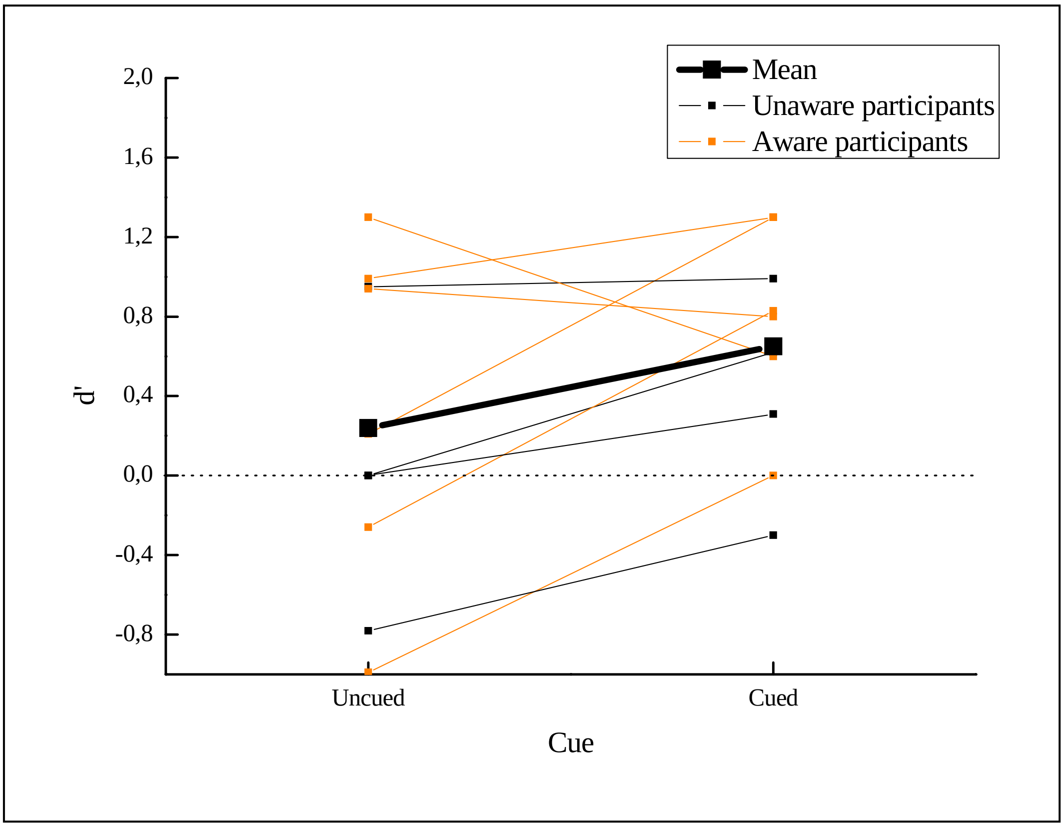


Fig. 5.6: The d’ values shown as the mean in Cue, and separately for individuals aware or unaware of configuration repetition.

### 5.2.4 Discussion

The aim of this experiment was to address the conflict of instructions given in Experiment 7a. Here, participants were again requested to memorize cued configurations and to respond to the search task but this time they could do so one after the other. Contextual cueing effect developed the same in the first epochs for cued and for uncued configurations. Astonishingly, in Epoch 5 responses to cued configurations started to become significantly faster than to uncued ones. The effect even enlarged in Epoch 6. A potential explanation can be found, by considering findings concerning generation of conscious awareness in implicit learning tasks. Haider and Frensch (2005), for example, found response times of participants aware of a specific rule underlying the task decreased much faster from the beginning than response times of participants unaware of this rule. In fact, group means never reached the same level and response time differences increased further during the task. This finding might account for the data in the present experiment, too. Cued configurations should have been explicit from the beginning and thus could have led to a larger decrease in response times than implicit learned configurations. Yet, learning cued configurations might have been too difficult and thus may have needed a certain amount of repetitions. However, this can not explain why this shift in response times in the last two epochs was abrupt and not smooth, since it is unlikely that all cued configurations became explicit at the same time. The finding remains puzzling but also raises the question whether the implicitly learned configurations can eventually become explicit, too.

In the recognition test mean accuracy for uncued configurations did not differ from chance but accuracy for cued ones differed highly significant. As anticipated more participants noticed repetition of uncued configurations. This did neither influence magnitude of contextual cueing nor performance in the recognition test compared to the unaware participants. These findings can be taken as good evidence that participants were able to follow instructions this time. Memorization of cued configurations was possible during presentation without vertical lines. At the same time uncued configurations were not memorized explicitly. Most participants noticed very late in the experiment that some of the uncued configurations were also repeated.

In sum, contextual cueing was found for cued and for uncued configurations. Cued configurations could be recognized explicitly to a large extend and uncued configurations remained implicit. Remarkably, from Epoch 5 on, the contextual cueing effect for explicit learned configurations started to increase more than the effect for implicit learned configurations.

## 5.3 Experiment 7c

### 5.3.1 Introduction

The experiment had two major aims. First, it should replicate the findings of larger contextual cueing effects in the explicit learning condition found in Experiment 7b. Second, the experiment addressed the question whether implicit learned configurations finally become explicit after more repetitions. The method of Experiment 7b was used again and tested with new participants. Yet, the experiment was extended to two sessions resulting in 60 repetitions of every configuration. The recognition test was conducted after the second session.

It was expected that findings of Experiment 7b could be replicated and that all participants notice repetition of uncued configurations. In the recognition test cued and uncued configurations should be recognized explicitly.

### 5.3.2 Materials and methods

Details were the same as in Experiment 7a, except for the following changes.

*Participants.* 10 students (three male) from the University of Braunschweig, aged 19-46 years, (mean: 26.5 years) were tested in two one hour sessions. All of them took part for course credit. None of the participants took part in one of the former experiments.

*Layout of experimental sessions.* The experiment consisted of two sessions which contained 30 blocks each with 24 configurations, summing up to a total of 1440 trials. Thus each configuration was repeated 60 times. 12 configurations were of the type Variable. Those configurations were not cued. Six configurations were of the type Fixed provided with a cue in advance of the trial and six further configurations of the type Fixed remained uncued. The recognition test followed immediately after the search task and contained only configurations with the fixed target.

### 5.3.3 Results

Figure 5.7 shows mean response times for cued and uncued fixed configurations compared with the baseline configurations of the type Variable. A contextual cueing effect was found from Epoch 3 on. As in the other experiments of the present work participants improved throughout the experiment. Since the design was nested an ANOVA including factors Configuration and Epoch was conducted and another one including factors Cue and Epoch. The former ANOVA revealed significant main effects of Configuration [$F(1,9)=22.24$, $p=0.001$] and Epoch [$F(11,99)=38.25$, $p<0.001$]. The interaction Configuration x Epoch reached significance [$F(11,99)=9.36$, $p<0.001$]. To compare results with Experiments 7a and 7b the interaction contrasts restricted to first and sixth epoch, which was the last epoch in the other experiments, was also investigated. It reached significance [$F(1,9)=15.60$, $p<0.003$]. Likewise did the interaction contrast restricted to first and last epoch [$F(1,9)=32.30$, $p<0.001$] The second ANOVA showed that the main effect of Cue did not reach significance [$F(1,9)=1.85$, $p=0.207$]. The main effect of Epoch was confirmed [$F(11,99)=35.13$, $p<0.001$]. The interaction of both factors did not reach significance this time [$F(11,99)=1.38$, $p=0.194$]. Post-hoc tests revealed significant interaction contrasts for the fifth [$F(1,9)=6.67$, $p=0.030$] and sixth [$F(1,9)=6.15$, $p=0.035$] epoch and also for the 11$^{th}$ [$F(1,9)=4.83$, $p=0.050$] and 12$^{th}$ epoch [$F(1,9)=6.01$, $p=0.037$].

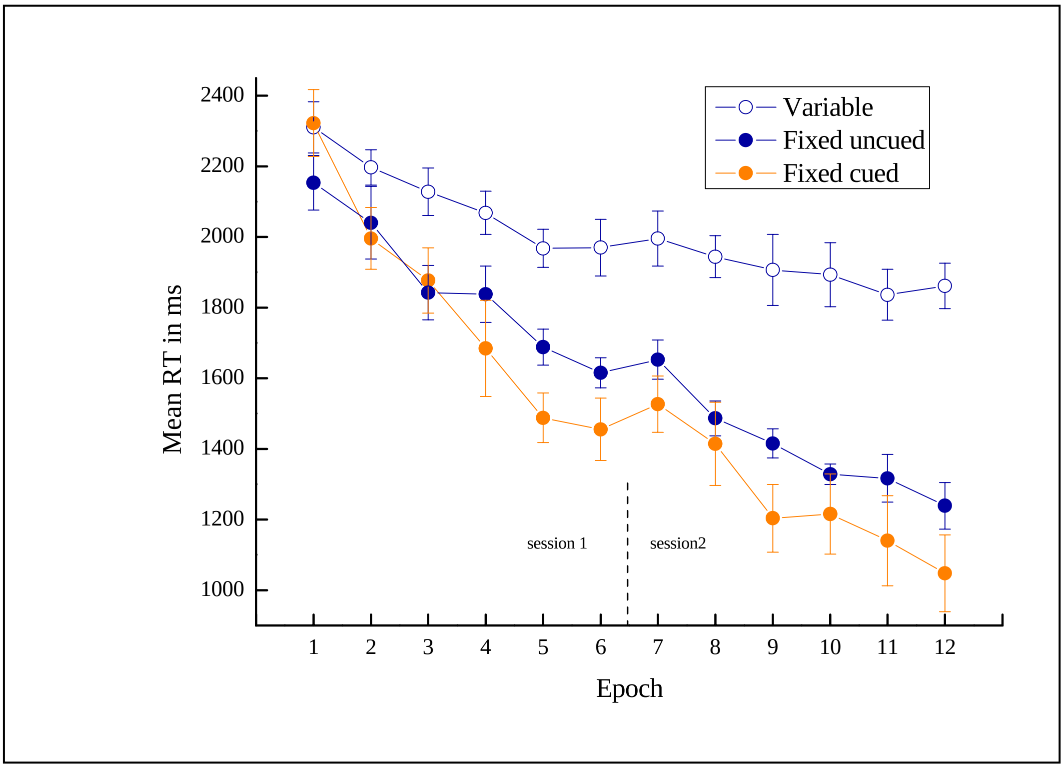


Fig. 5.7: Mean RT for cued and uncued configurations in comparison to condition Variable across epochs.

*Contextual Cueing:* The magnitude of contextual cueing was estimated separately for both levels of Cue against the mean of Variable. For uncued configurations the magnitude was 288ms in Epochs 4, 5, and 6 [$t(9)=3.36$, $p=0.008$] and 566ms in the last three epochs [$t(9)=6.04$, $p<0.001$]. For cued ones it was 459ms in Epochs 4, 5, and 6 [$t(9)=3.64$, $p=0.005$] and 726 ms in the last three epochs [$t(9)=4.83$, $p=0.001$]. All results differed significantly from 0.

*Evidence for implicitness:* None of the participants guessed the original purpose of the experiment. All participants noticed repetition of the uncued configurations this time. Most of them did in session two.

*Recognition test:* Data were analyzed separately for Cue levels. Mean accuracy in the recognition test was 68.9% for uncued configurations and 79.0% for cued ones. The corresponding mean d' values for forced choice tasks were 0.73 and 1.15, respectively. Results differed from 0 significantly in the case of uncued configurations [t(9)=3.22, p=0.010] and also in the case of those that were cued [t(9)=5.78 p<0.001]. The mean d' values are shown in figure 5.8, which includes also the d' values for each participant separately.

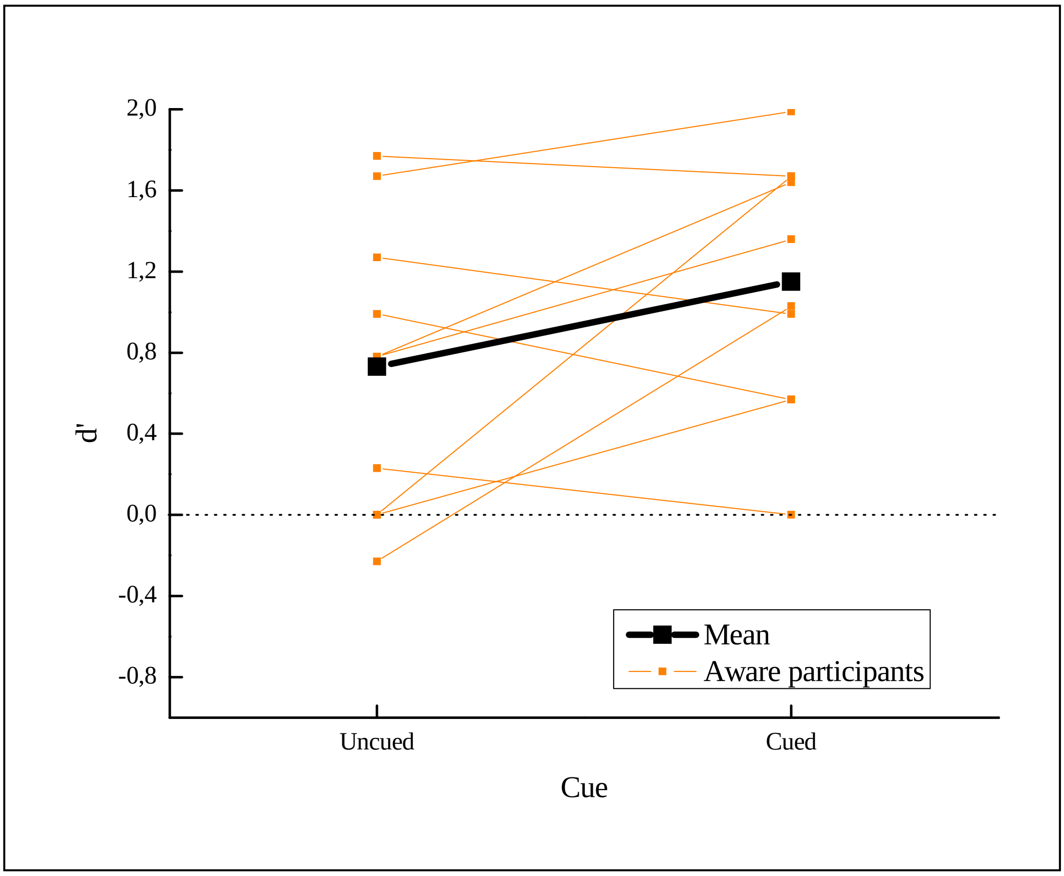


Fig. 5.8: The d' values shown as the mean in Cue, and separately for individuals.

### 5.3.4 Discussion

The findings of Experiment 7b were successfully replicated. Again, a contextual cueing effect was found for cued and for uncued configurations. The effect for cued configurations increased more than the effect for implicit learned configurations from Epoch 5 on. Remarkably, the contextual cueing effect for cued and uncued configurations did not differ in the beginning of session two, but the different learning curves developed again during the experiment.

Promising findings were made in the recognition test. All participants noticed configuration repetition. Mean accuracy in the test was above chance in both levels of Cue. Compared to Experiment 7b, performance in the uncued condition after 60 repetitions was as high as performance for cued configurations after 30 repetitions. The question whether uncued configurations eventually become explicit can be answered with a yes. It just takes more time.

Critical is that participants were not at 100% correct for cued configurations after 60 repetitions. This could be an indication that the recognition test is too difficult and therefore a rather conservative test. However, this is unlikely because this result could also indicate that configurations that are very similar are difficult to learn. Support comes from the finding that response times for cued configurations did not decrease much faster in the beginning.

In sum, the last three experiments showed again that the paradigm is ideal to study implicit learning effects since it takes much effort to learn the configurations explicitly. Nonetheless, it was demonstrated that this was possible after a certain amount of training.

# 6. General Discussion

The present experiments gave clear evidence for implicit learning of spatial context. The aim of this work was to extend the findings on contextual cueing.

*Implicit learning of spatial context in preattentive search.* Experiment 1 demonstrated for the first time that contextual cueing does not occur in pop-out search. In addition, the experiment successfully replicated contextual cueing in serial search by using newly constructed stimulus material. In pop-out search, responses were made much faster than in serial search. Thus, it could not be excluded that search in the pop-out condition was already maximally efficient (ceiling effect). None of the participants guessed the purpose of the experiments or noticed repetition of configurations. This was taken as an indicator for the implicitness of this learning process.

The learning task used in experiment 1a satisfies the standard of an implicit learning paradigm. This evaluation was based on the criteria of Dienes and Berry (1997) (see introduction). First, the learning effect revealed specificity of transfer, since learning did not generalize to any new configurations. Second, if the subjective report of the participants is used as a valid criterion then their acquired knowledge is inaccessible. Further evidence for the inaccessibility was found in the other experiments using objective tests. Third, learning can be considered incidental since no instructions were given about repeating configurations and none of the subjects guessed the purpose of the experiment. Fourth, the criterion for robustness across time can also be affirmed, since contextual cueing effects were found although sessions could be two days apart. The criterion that implicit learning is usually bound to surface features of the stimulus material was not investigated. Nonetheless, it can be safely concluded that the used paradigm is an implicit learning paradigm.

Experiments 1b investigated whether participants in experiment 1a had learned configurations in pop-out search but were already at their response limit (ceiling effect). In a further testing session pop-out configurations were shown in the serial search task and vice versa. If participants had implicitly learned configurations in pop-out search, they should have shown contextual cueing from the beginning or at least facilitated learning. However, contextual cueing effects developed regularly. This finding led to the conclusion that contextual cueing in preattentive search does not exist, presumably because it is unnecessary since responses are maximally fast. Further support came from the serial search configurations of Experiment 1a which were shown in the pop-out condition in Experiment 1b. No further speed-up of responses was found although configurations were already implicitly learned.

Experiment 2 contrasted two search conditions with search durations in between serial and pop-out search of Experiment 1a. Results showed that the contextual cueing effect evolved along the transition from preattentive to attentive search. This leads to the conclusion that configurations are implicitly learned when search is not efficient enough anymore. In other words, the longer the search takes, the larger the contextual cueing effect. In addition, learning effects enlarged even after 45 repetitions of the configurations. Remarkably, in an adjacent recognition test participants could still not distinguish repeated from new configurations, which is clear evidence for the implicitness of the effect. This result extends the findings of Chun and Jiang (1998) who found that participants were unable to distinguish configurations after 30 repetitions. A Simon effect (Simon & Rudell, 1967, Simon, 1969) was not found in this experiment. Presumably, instruction and reading order were responsible for different RTs across display positions. Since target locations were chosen randomly in repeated and new configurations this confounding factor was balanced though.

*Effects of repeating spatial configurations without a fixed target location*. Experiment 3 replicated the finding that if configurations were repeated but the target was allowed to vary freely across all distractor locations contextual cueing did not occur (Chun & Jiang, 1998). Chun and Jiang (1998) concluded that the contextual cueing effect can not be simply ascribed to an increasing efficiency in searching through repeated configurations but rather it represents associative learning between the target location and the surrounding distractors. In the present work it was also found that responses for configurations with a variable target location did not differ from new configurations. Therefore, repeated configurations with a fixed target location were always contrasted with repeated configurations with a variable target location in the following experiments. In this way all configurations in the experiment were repeated which was expected to raise the likelihood for detection of repetition. Thus, the question whether awareness influences contextual cueing could be further investigated.

*Robustness of implicit learning of spatial context.* Experiment 4 focused on the question of robustness of contextual cueing effects against jitter of items in the configurations. Large jitter should lead, if at all, to the smallest learning effect. The largest learning effect should be obtained when configurations were kept unvaried throughout the experiment. The results showed a contextual cueing effect for all conditions and the largest for configurations that were not jittered. No graduation was found in between small and large amounts of jitter. Nonetheless, it has been demonstrated that contextual cueing effects emerge even with large jitters in every trial.

A new explicit recognition test was introduced in Experiment 4. Participants were confronted with two versions of a repeated configuration reduced in size. One was the original as seen throughout the experiment. The other was a fake in which the target and one distractor switched locations. The task was to decide which configuration was the original. Participants were not able to discriminate the original from the fake configuration above chance.

The introduced recognition test is considered a superior alternative to the tests developed by Chun and Jiang (1998, 2003). In 1998 they used the repeated/new discrimination also applied in Experiment 2 of the present work. Chun and Jiang (2003) pointed at the limitation of this test since the test is based on a sense of familiarity for the configuration. They argued that such a measure may be too insensitive for explicit memory as it reflects memory traces that may be different from those used to benefit target localization in search. Chun and Jiang (2003) therefore introduced a different test with the intention to improve the sensitivity and validity of the explicit recognition test. Especially, Chun and Jiang (1998) wanted to increase the similarity between the learning task and the recognition test as demanded by Reingold and Merikle (1988) and Shanks and St. John (1994). Repeated and new configurations were presented in which the target was substituted by a distractor. Participants were to guess the monitor quadrant in which the target would appear. They were not able to do so correctly above chance level. Chun and Jiang (2003) argued that their task required the same type of knowledge that participants benefited from in the search task. However, the substitution of the target changes the configuration dramatically since the target is the most important landmark in this configuration. If contextual cueing is considered to be learning the location of the target in association with the surrounding distractors then testing the configuration without the target is probably an underestimation of the knowledge available. Further, the testing demands a free recall process which probably underestimates implicit knowledge because the typical finding is that recognition is usually superior to recall (e.g. Mandler, Pearlstone, & Koopmans, 1969; Kintsch, 1970).

The test used in the present work has several advantages. First, for the reason just mentioned a recognition procedure was used. Second, the target was included in the configurations which should facilitate recognition. Finally, testing is similar to the learning phase because a visual search for the target is necessary first. Participants have to decide then what search process seemed more familiar to them. Note the difference between the decisions of familiarity in the repeated/new test, in which it is uncertain whether participants decide on the fact whether the configuration or the search process seems familiar and the decision in the original/fake test. In the original/fake test, it is assured that the decision is made on the familiarity of the search process, which is thought to be origin of the contextual cueing effect (Peterson & Kramer, 2001).

Experiment 5 focused on the question whether conspicuous configurations lead to larger learning effects than configurations with evenly spread stimuli. Contextual cueing was found in homogeneous and in inhomogeneous configurations which did not differ significantly from each other. Thus, implicit learning works well for both, conspicuous and inconspicuous configurations. An analogy can be drawn to findings of Loftus and Bell (1975). They compared recognition memory for complex (photographs) and not-complex (line drawings) pictures with the hypothesis that more informative areas in a picture, as found in photographs, would lead to better recognition performance. Memory performance was found to be substantially unaffected by picture complexity, given that participants had encoded at least one potential informative area in a certain picture. These findings can be assigned to the results of Experiment 5, if one assumes that the target and the surrounding distractors are an informative area in the configuration. Thus, it should not matter how distinctive the whole configuration is.

The recognition test in Experiment 5 replicated that participants were not able to discriminate original from fake configurations. Further, evaluation of the different distances produced by the switch of the target with a distractor in the fake configuration showed that distance had no effect on performance. If the target switched with a near distractor performance was as poor as if it switched with a far distractor. Noteworthy, contextual cueing effects are not dependent on awareness of configuration repetition or on recognition performance.

In Experiment 6 it was investigated whether correlating the response with the configuration would influence learning effects. In all former experiments, participants could not anticipate which response had to be given, although they had implicitly learned the configuration. A stimulus-response association was expected to facilitate contextual cueing. However, a correlation of response and configuration had no influence on contextual cueing effects. Further, the correlation did not even lead to better performance in the explicit recognition test. The findings are puzzling since a stimulus-response association was expected to occur, since this seems easier to learn than the whole target-distractor context. It can be speculated that the configurations were to complex and to similar to show a stimulus-response association.

*Explicit and implicit learning of spatial context.* Experiments 7a, 7b, and 7c investigated whether configurations could be explicitly learned by requesting participants to do so. Therefore, some repeated configurations were cued. Contextual cueing for these configurations was compared to the effect of configurations that were also repeated but not cued. In Experiment 7a learning effects did not differ for cued and for uncued configurations but simultaneously results of the recognition test suggested that participants were not able to learn cued configurations. This was probably due to conflicting instructions. Therefore, in Experiment 7b participants were allowed to accomplish instructions one after the other. Results indicated that manipulation succeeded and participants were able to fairly memorize cued configurations. Learning effects for cued and uncued configurations developed the same in the first epochs and then the effect for cued configurations increased more than the effect for uncued configurations. This might have occurred because cued configurations were not explicit from the beginning but became explicit during the experiment.

Experiment 7c replicated the finding that learning effects for cued configurations increased more than the effect for uncued configurations in later epochs and investigated whether uncued configurations could eventually become explicit after more repetitions. Results clearly demonstrated that implicitly learned configurations become explicit after more repetitions. Nonetheless, it was difficult for participants to explicitly memorize the configurations, although memory for pictures seen just once is amazingly good (e.g. Standing, Conezio, & Haber, 1970). Difficulties raised probably from the fact that the stimuli used here were not as complex as real world scenes.

Open is the question how implicit and explicit processes interact in the contextual cueing paradigm. Research still disagrees about one or multiple memory systems for implicit and explicit learning. Frensch et al. (2002) assume multiple memory systems but also that implicit learning precedes explicit learning. Explicit learning processes are even thought to be triggered by the implicit ones. Sun, Merill, and Peterson (2001) and Reber (1989) pointed out that nearly all complex skills in the real world involve a mixture of explicit and implicit processes interacting in complex ways.

*Conclusion*. Taken together, the experiments presented here show that implicit learning of spatial context is found under several conditions implying that contextual cueing effects are very robust. The used stimulus material was found to be ideal to study implicit learning effects since the configurations take a long time until they can be memorized explicitly. Contextual cueing is modulated by the search type (serial search superior to pop-out) and by the amount of repetitions (the more repetitions, the larger the effect). Further, contextual cueing is robust against large jitter of the configurations which is probably due to generalization processes. The effect does not depend on the homogeneity of the configurations and an unvaried response to a certain configuration does not enhance contextual cueing. Furthermore, configurations are difficult to be learned explicitly, but for those learned, contextual cueing increases more than for implicit learned configurations. Moreover, results of the new recognition test corroborate the implicitness of contextual cueing.

The present experiments demonstrate that our implicit learning system is a powerful mechanism that guides our behavior efficiently without the necessity to reach awareness. Evidence was found that context plays an influential role in our perception processes. The results showed that contextual cueing effects are not as inflexible as implicit knowledge is usually expected to be (Dienes & Berry, 1997). Quite the contrary is true, contextual cueing was found under a variety of manipulations. Future research should focus on limitations of contextual cueing. For example, it remains unsolved how much the context can change until the learning effect is no longer observed.

Another open question is how the present results can be integrated in real-world scene perception. First attempts have been made to investigate contextual cueing in naturalistic scenes (Brockmole & Henderson, 2006; Brockmole, Castelhano, & Henderson, 2006). However, these studies deal with the problem to demonstrate learning processes are implicit, since in real-world scenes memory for target-context covariations is usually explicit. Meaningless configurations as used in the present experiments have the advantage that implicit learning processes can be demonstrated. Therefore, it would be important to integrate the insights on contextual cueing in meaningless configurations and in naturalistic scenes.

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